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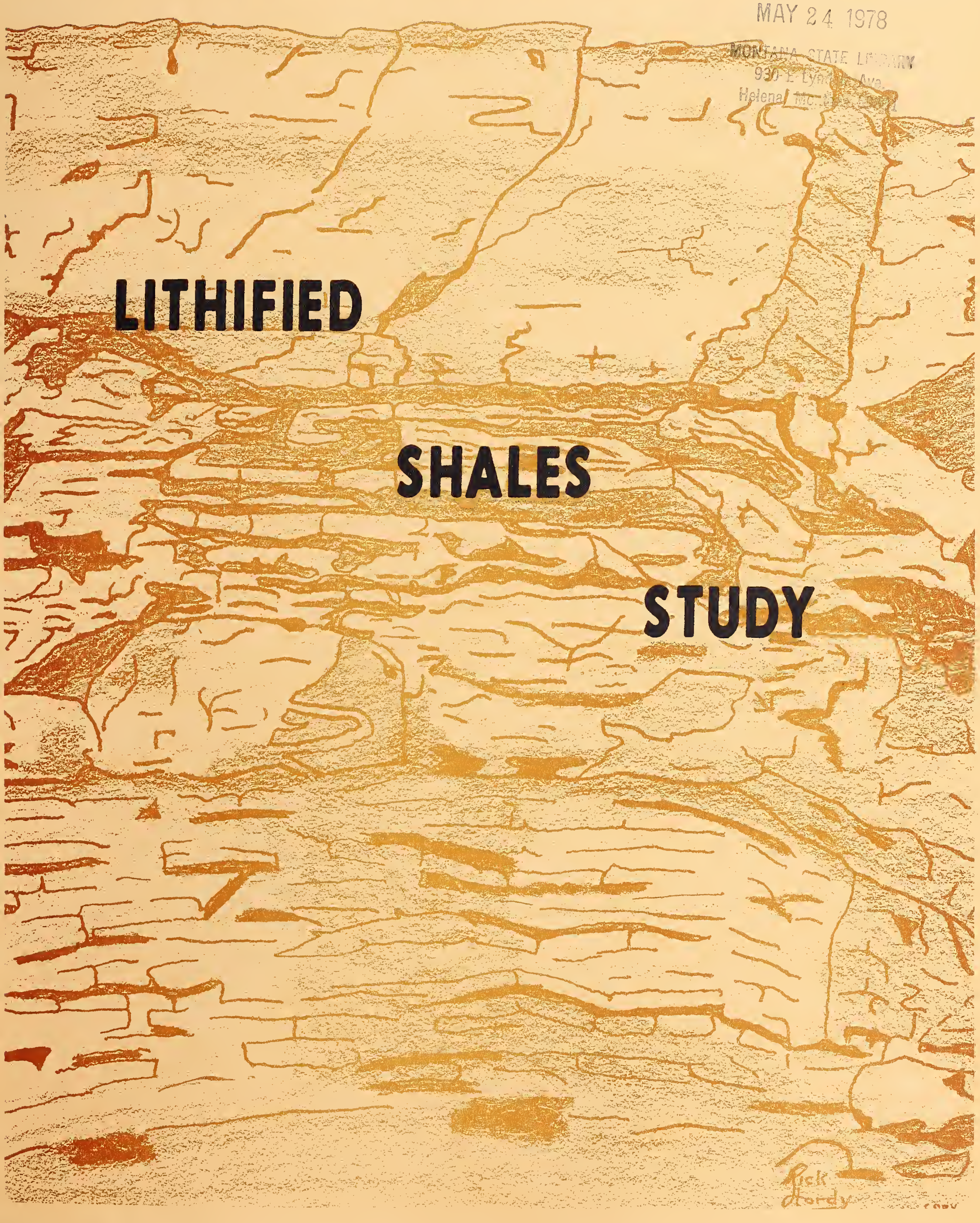

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LITHIFIED SHALE PROJECT
REPORT OF INVESTIGATION

by

Department of Engineering Science

Montana College of Mineral Science and Technology

Francis M. Young, P.E.
Richard B. Rule, II

Prepared for

Montana State Highway Commission
Planning Survey Section

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Montana State Highway Commission or the Federal Highway Administration.

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FINAL REPORT

LITHIFIED SHALE PROJECT

STATEMENT OF THE PROBLEM

The objective of the lithified shale project was to study the changes that moderately lithified shales undergo after loading or unloading and the changes caused by variations in moisture content in the subgrade. The ultimate goal of the project was to acquire sufficient information so that highway design personnel could predict the results of the disruption of equilibrium conditions and could incorporate the predicted results into highway design.

The problem of this study was two-fold. First, the development and testing of devices capable of measuring pressure, moisture content, density, temperature, conductivity, pH, and movement, which could be inserted into drill holes for emplacement below excavation or fill. This first part of the problem included field testing of the devices at selected sites. The second part of the problem was placing the devices at selected sites for collection of data before and after construction and the interpretation of that data.

The research was organized into five phases. Phase 1 was a preliminary study of the literature on sensing and metering techniques which might be applicable to the problem. Phase 2 was the acquisition (either by purchase, modification, or construction) and testing of those devices which appeared to be usable for sensing the desired variable. In addition to studying the physical problem of inserting the devices into the ground, the characteristics and time changes of the instruments were to be studied.

Phase 3 was the testing of the durability and stability of the devices and the investigation of the problems involved in installation and data interpretation by installing the sensors and metering equipment at a convenient site.

The next phase, Phase 4, was insertion of the devices into drill holes at a site prior to construction. Natural equilibrium conditions were to be determined and periodic reading of the sensors were to be taken until equilibrium was again attained after construction was completed.

The last phase, Phase 5, was the study and analysis of the data, from which study it was anticipated that sufficient information could be attained so that the changes that moderately lithified shales undergo after construction could be predicted. It was hoped that these predicitions could be used in design or construction techniques to minimize the deleterious effects of such changes.

Unfortunately, because of difficulties encountered in field installation at the construction site, much pertainent data was not accumulated. The reasons for this loss and the effects on the results of the reasearch are discussed throughout this report.

TEST SITES

Instrumentation Test Site

The most important aspect of a field research project is the selection of the proper equipment. The equipment selected must be reliable, measure the variables with the desired sensitivity and accuracy. Because the location of troublesome shale was a great distance from the project headquarters, Butte, the reliability of the instruments was of foremost concern, particularly the reliability of the sensors when exposed to the severe winter conditions of the eastern Montana plains. Therefore, prior to the selection of the sensors to be used at the Cut Test Site it was planned to test each sensor at an Instrument Test Site, close to the headquarters. If the sensor tested proved to be reliable and performed satisfactorily, it would then be used at the Cut Test Site; if it proved unreliable an alternate method, or sensor, would be tested until a satisfactory sensor was found.

This Instrument Test Site, or Test Site One, was located seven miles west of Butte, Montana, along Interstate Highway 90, about one-half mile east of the Ramsey interchange (Fig. 1). The site, a highway fill containing montmorillonite clay, was ideal for its intended purpose; winter conditions were similar to those of eastern Montana where the actual highway cut would be instrumented, the material found in this test was similar to troublesome shale material, and the location was close enough to the Montana Tech Campus to make servicing of the site convenient.

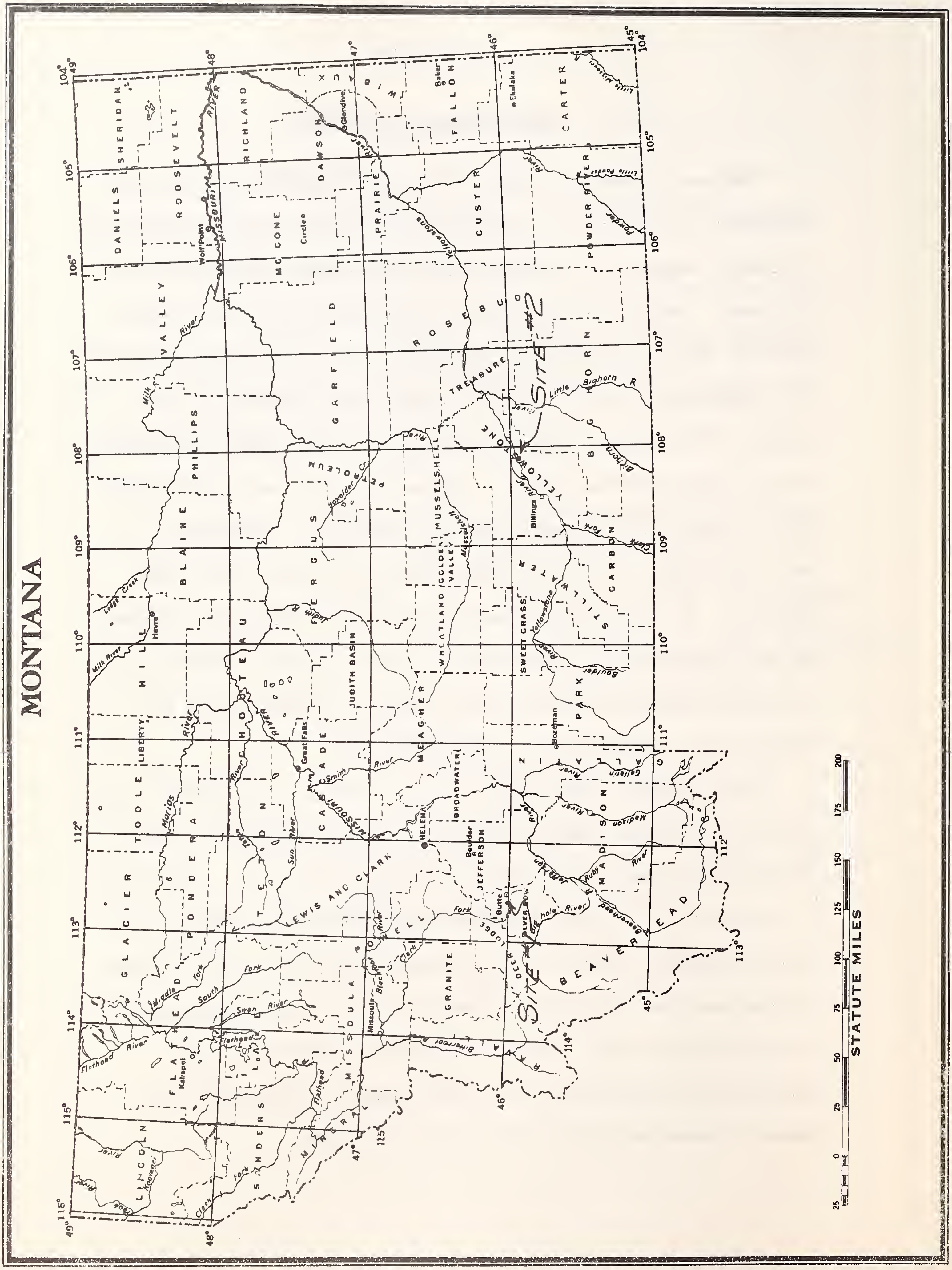

Figure 1 - Test Site Locations

The site was prepared on the shoulder of the roadway to avoid any disturbance of the traffic. Four three inch diameter holes were drilled into the fill to a depth of 30 feet and cased with steel pipe by drill crews of the Montana State Highway Department. Two additional seven inch holes were later augered to a depth of 20 feet and cased with plastic pipe to test the instruments that could not be tested in the four original holes.

Cut Test Site

The actual test site, Cut Test Site, or Test Site Two, was located on Interstate Highway 94 between Ballantine and Pompey's Pillar in Yellowstone County, in eastern Montana, approximately 40 miles east of Billings (Fig. 1). The site, Highway Station 2222, is the middle of a large cut where the highway descends from a bench to the valley floor. This is an area of rolling hills sloping from the bench land to the valley of the Yellowstone River. The area, naturally semi-arid, is now the location of considerable farming activity supported by the Huntley Irrigation Project. While the slope remains primarily semi-arid there was, prior to construction, some ground water in the area, a low volume spring approximately 1,000 feet east of the location. The geology of the site is Bearpaw Shale dipping less than one degree easterly overlaid with gravel between 30 and 40 feet in thickness. (Fig. 2).

Prior to selection of this site a preliminary investigation consisting of field observation and test coring was conducted. This investigation demonstrated that the site would be satisfactory;

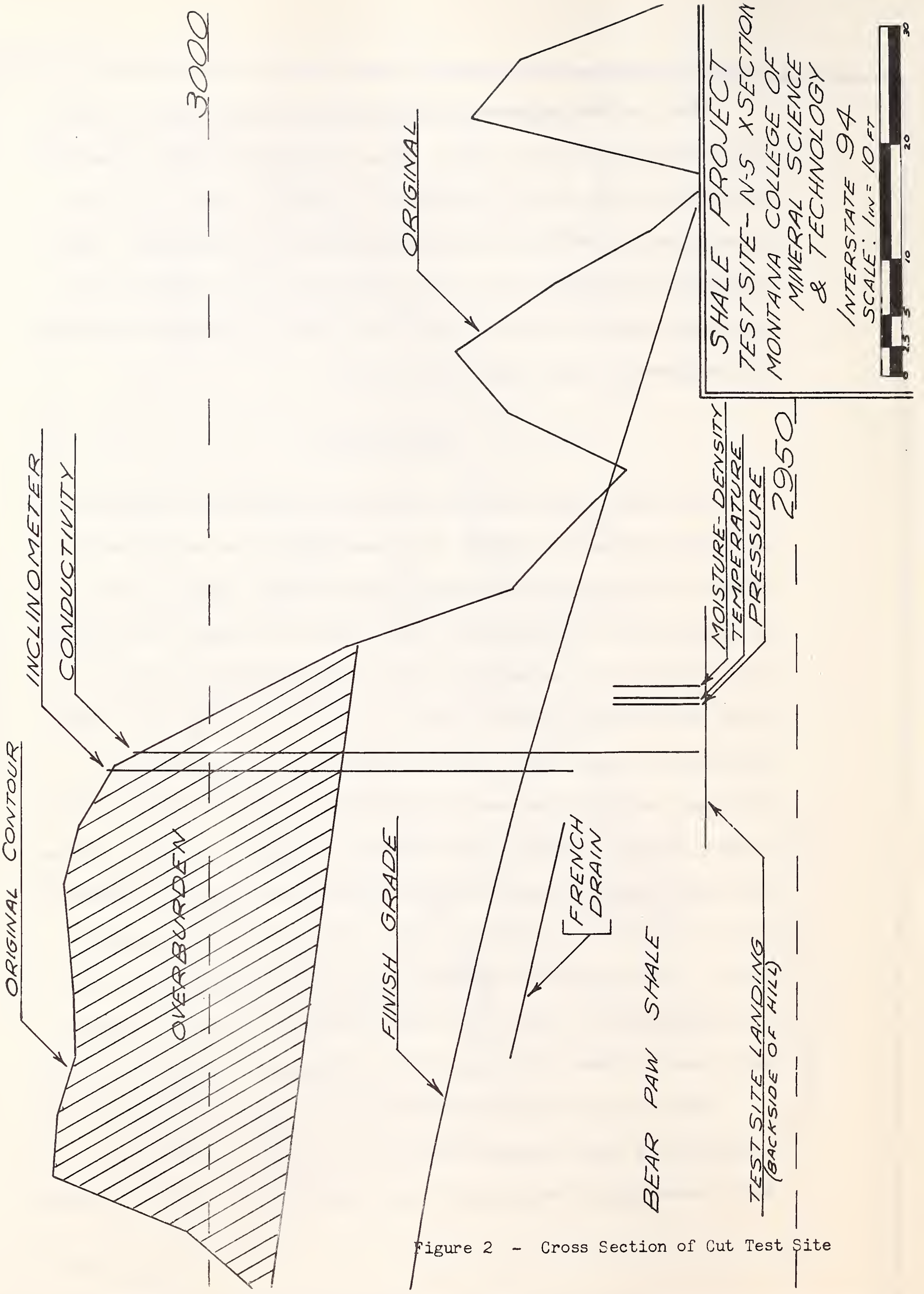

Figure 2 - Cross Section of Cut Test Site

the bottom of the cut would contain the shale material being investigated, enough overburden would be removed to significantly unload this shale layer, and the site would be easily accessible in all types of weather and through all phases of construction. It was located just off Canal Road, a county and Huntley Project road, which services the adjacent irrigation canal and also served as a school bus route until construction was completed; therefore, this road was well maintained and kept open whenever possible. This section of Interstate 94 scheduled for bid letting in September, 1967, and the preliminary investigation was conducted in March, 1967, allowed all summer for further investigation and installation of the sensors.

This site appeared to be satisfactory but one serious problem arose. In order to locate the readout site in the median of the highway and to interfere with the normal progress of the construction, it was necessary to secure approval through the proper government channels in Helena, Montana; Portland, Oregon; and Washington, D.C.. Permission was not granted, necessitating a complete change in plans for the test area. To further cause difficulty the letter denying this permission was not received until August 15, 1967, creating a very serious time problem. This decision, that neither the readout site nor any other equipment could not be located on the highway right-of-way, at first seemed to greatly limit the capabilities of the study; but it was decided to continue at this location because this was the only section of roadway suitable for such a study scheduled for construction at that time.

Further investigation indicated that the problem could be solved. The cut at Station 2222, when completed, would leave a knob hill remaining to the north so it was decided to utilize this hill by drilling three horizontal holes from the back of it, terminating about three to five feet below the finished subgrade under the centerline of the west bound lane (Figs. 2 & 3). For those sensors which could not be adapted to horizontal holes, two vertical holes were drilled one foot off the right-of-way on the top of the hill (Fig. 5). Even with this problem solved, the lack of time made it impossible to monitor the pre-construction values of the variable by installing the sensors prior to construction as originally planned.

Undisturbed Site

In order to obtain preconstruction values of the variables being monitored, so that they could be compared with those measured at the Cut Test Site, during and after construction; to detect the effect of construction on the variables it was necessary to choose another site in the same area, but far enough away from the construction to be unaffected by it. This Undisturbed Site had to be easily accessible in all types of weather because the sensors at this site would be read at the same intervals as those at the Cut Site. A suitable location, an old abandoned gravel pit, which is located 900 feet south of the east bound center line at Station 2190, was chosen (Figs. 7 & 8). The pit was far enough from any construction to be unaffected by it and was adjacent to a main north-south county road making it easily accessible.

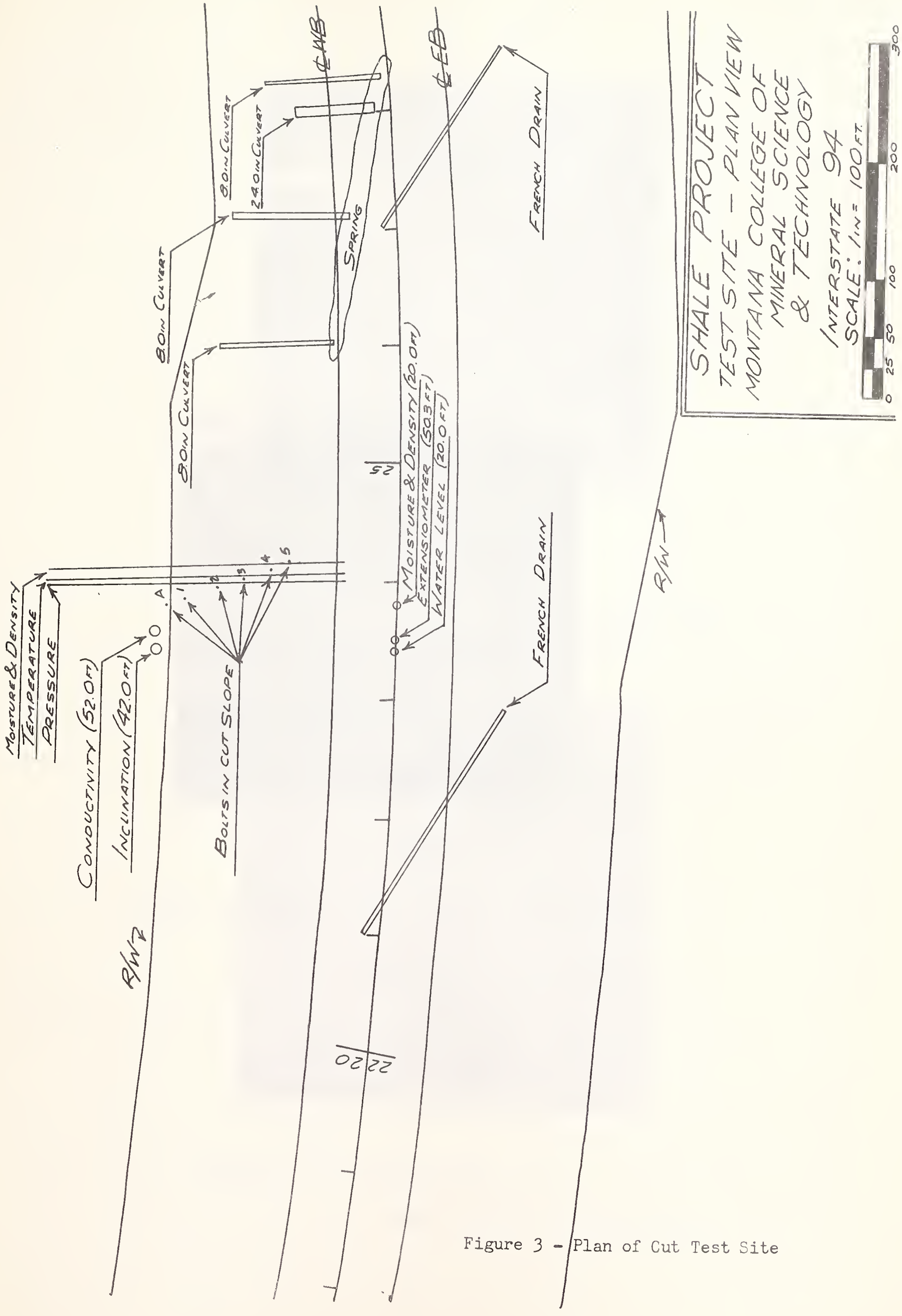

Figure 3 - Plan of Cut Test Site

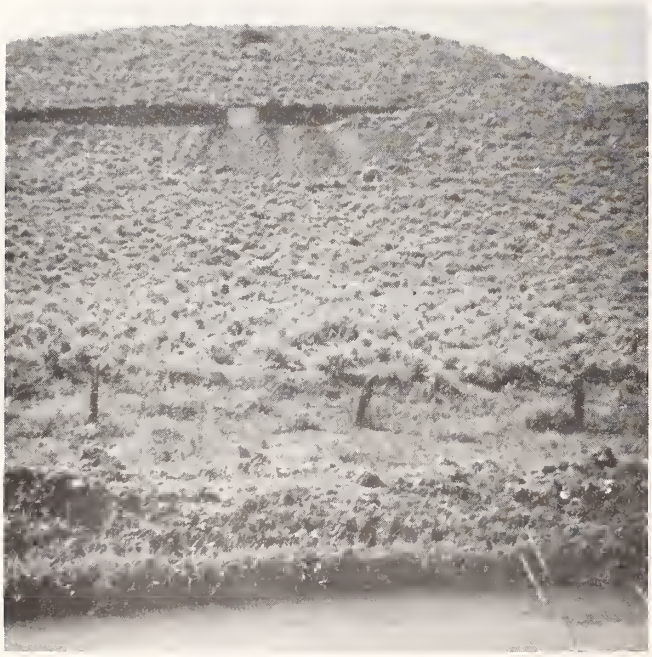

Figure 4 - Cut Test Site Readout Location

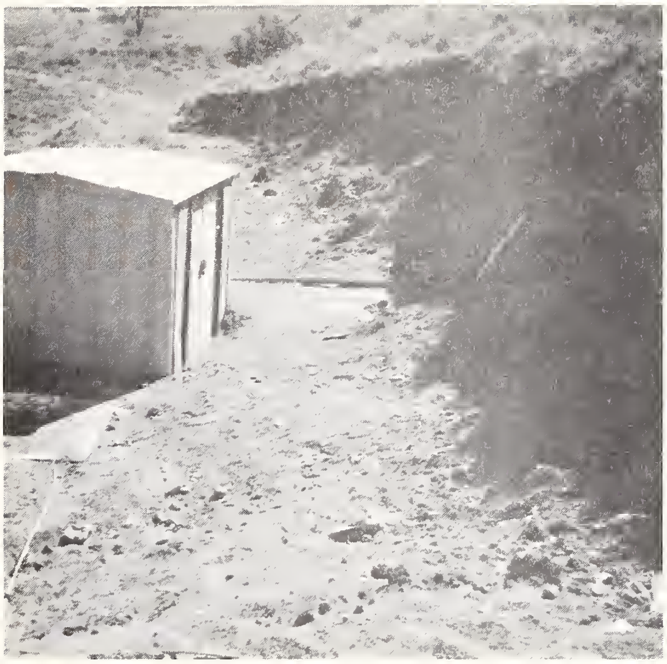

Figure 5 - Cut Test Site

Horizontal Hole Collars and Readout Station

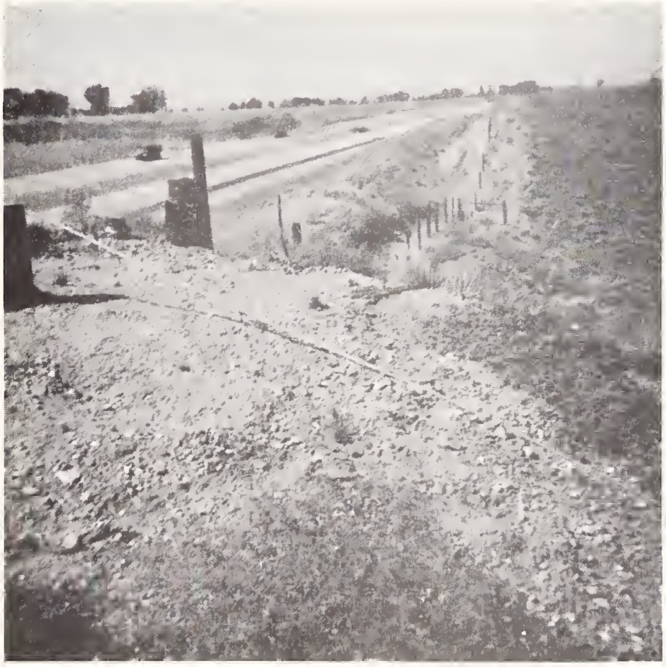

Figure 6 - Cut Test Site

Vertical Holes on Hill Crest

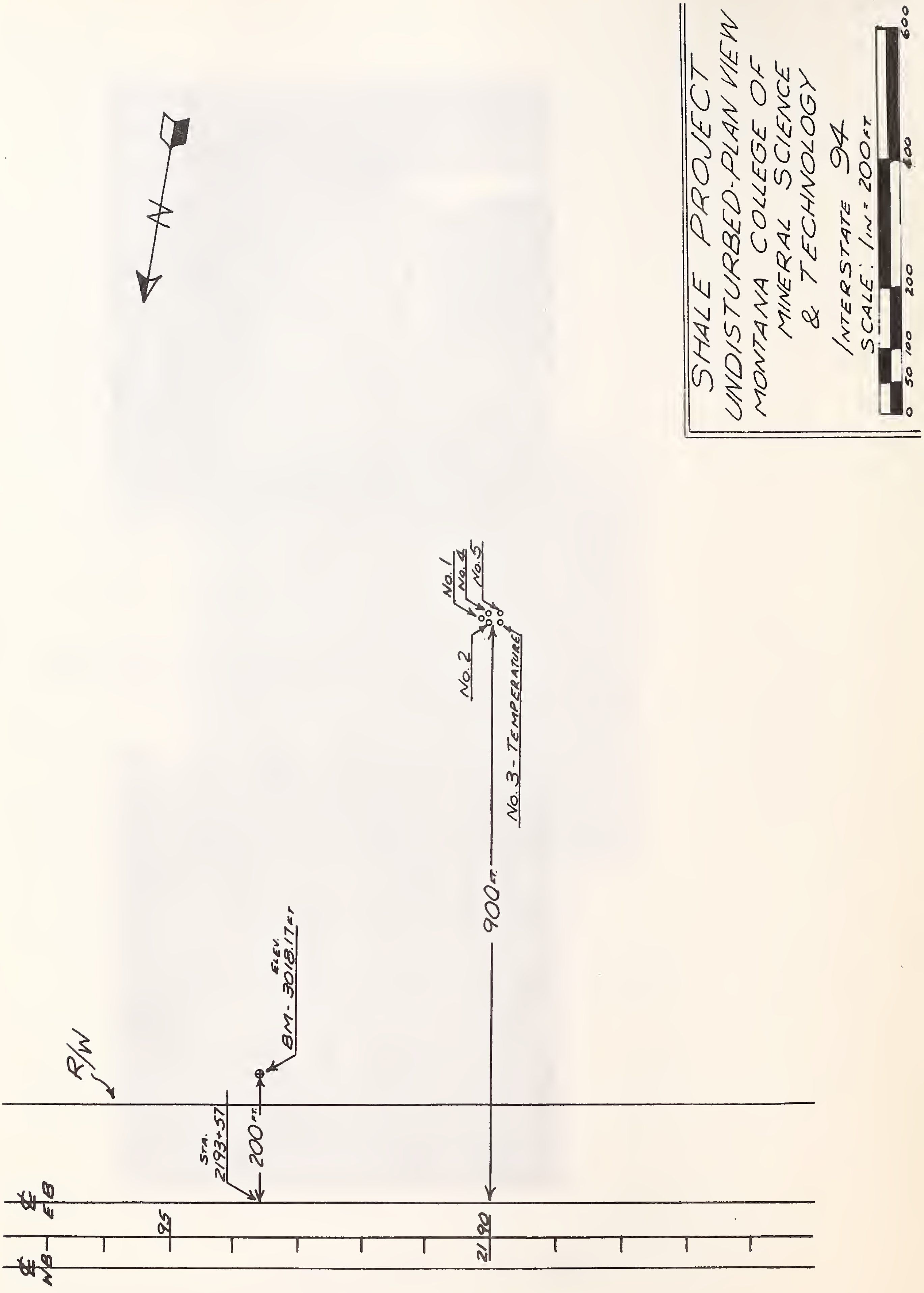

Figure 7 - Undisturbed Site Location

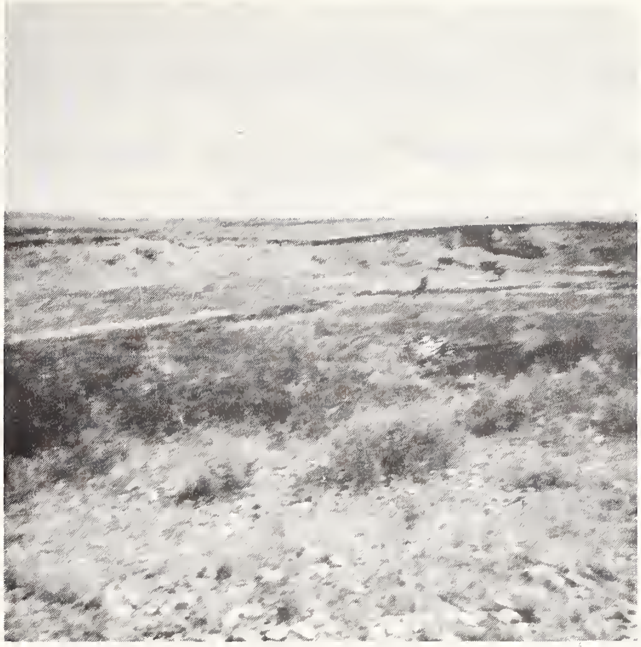

Figure 8 - Undisturbed Site

Showing Overburden Removed

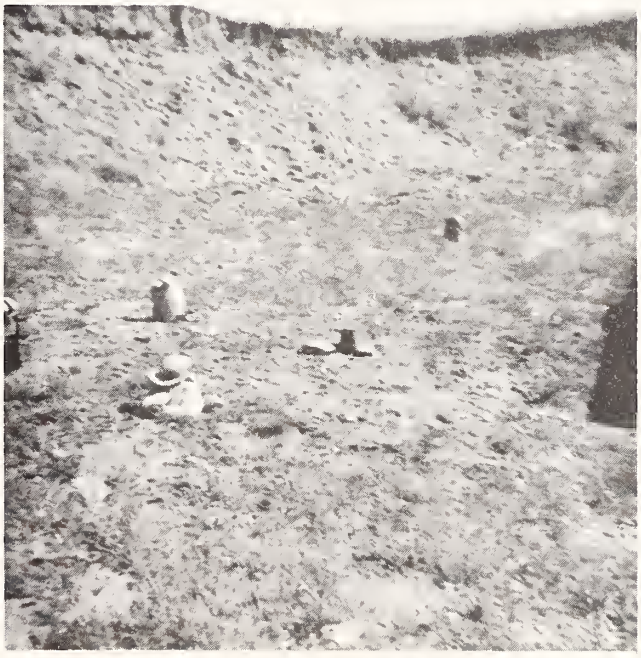

Figure 9 - Undisturbed Site, Close-up

At this site five vertical holes 50 feet deep were drilled, all contacting the Bearpaw Shale with about six feet of overburden. All of the holes also contained ground water with a static level of 21 to 21.5 feet, making the site useless for its intended purpose. Because the holes drilled off the right-of-way at the Cut Site had encountered only a small amount of ground water and therefore it was felt that the shale at the Cut Site and Undisturbed Site had not been exposed to identical preconstruction conditions. While the site could not be used for its intended purpose, it was felt that it did offer an opportunity to measure the variables of shale that was completely submerged which, when compared with the variables obtained at the Cut Test Site, could aid in determining the effect of free water on the shale.

INSTRUMENTATION

Pressure

The aim in monitoring the pressure of the soil mass was to determine if it would be possible to correlate any volume change with an accompanying pressure change. It was also thought that by correlation of other data with the pressure data it may be possible to relate the changes in other variables to any volume or pressure changes. The sensor used to monitor the pressure was a Geocel 00 pressure captor. The instrument consists of a rubber bladder about three feet long, sealed at both ends around wood dowels 3/4-inch in diameter. The bladder is attached to the readout equipment, a Bourdon type pressure gauge, with ½-inch, nylon, pressure tubing. The entire system is filled with a mixture of ethylene glycol and water; this fluid acts as an agent to transmit the pressure from the bladder to the gauge where it may be observed.

The pressure call was installed at the Instrument Test Site and functioned flawlessly. The instrument was then removed from the Instrument Site and installed in a freshly drilled 4½-inch, 256-foot, horizontal hole with a +2½% grade. The hole was drilled using air as the circulatory agent for the first 170 feet but when the hole began to seep ground water it was decided to use water as the circulation agent for the last 90 feet since the natural condition of the soil would not be disturbed, and the drilling would be easier. The first 240 feet of this hole was then cased with three-inch plastic pipe. The end of this hole, which was approximately six feet below the finished subgrade of the center line of the west bound lane, was left uncased so that the bladder could be placed outside the casing. The bladder was placed 250 feet from the collar, because at that position the bladder would be free of any influence from either the casing or the end of the hole.

To install this pressure monitoring system the entire system was evacuated to assure the absence of any air or liquid. The system was then filled and pressurized to give the bladder sufficient rigidity to allow it to be pushed into position. It was positioned using aluminum electrical conduit as a pushrod; ten-foot lengths of the conduit were coupled using standard couplers to form a rigid pushrod. The bladder was held to the pushrod as shown in Figure 10. After the bladder was positioned the pushrod was left in place to assure that the bladder would not move from the desired position until it had been pressurized. The system was pressurized, using the pressurizing equipment shown in Figure 11. This was done in steps in order to assure no damage would be done to the bladder or gauge and that the final pressure attained would be as close to the natural pressure of the soil as possible. Pressure was applied until it began to climb rapidly, indicating that the bladder had come in contact with the drill hole walls; pressurizing was then stopped while the walls of the hole were allowed to relax, reducing the pressure on the bladder. The bladder was then repressurized and the cycle repeated several times until there was no appreciable pressure drop after the

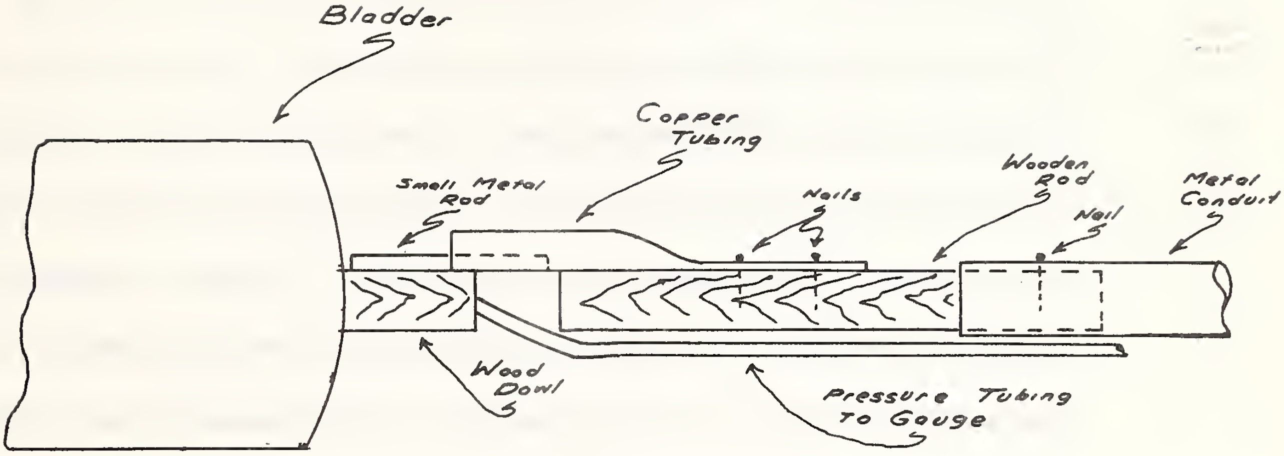

Figure 10 - Pressure Bladder Pushrod Assembly (latch-up)

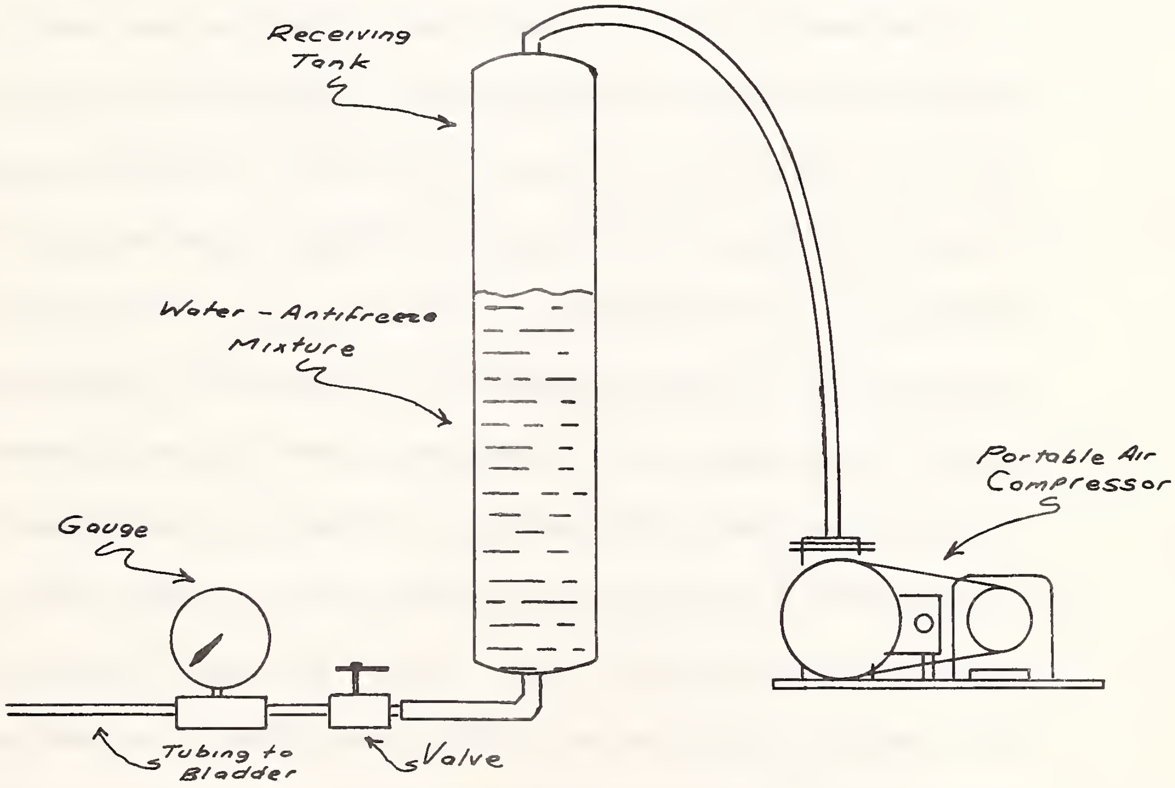

Figure 11 - Pressurizing equipment

repressurizing. At this time the bladder pressure was close to being equal to the pressure of the shale and the only correction necessary was for the hydrostatic head of the system. An alternate method of installation is to pressurize the bladder to half range of the gauge then allow the bladder to slowly depressurize until it attains the natural soil pressure, usually about 10 days for shale. While the second method is more accurate and preferred by many users of this type of pressure sensor, it was necessary to risk the inaccuracy of the rapid method because clearing and grubbing operations had been completed and some cutting had begun on the date of installation and it was important to monitor all pressure changes caused by construction.

Because the captor used at the Instrument Test Site and then reused at the Cut Site had performed without difficulty, a similar unit was ordered and an attempt was made to install it in a $4\frac{1}{2}$ inch hole at the Undisturbed Site; this bladder burst during installation procedure. It was found to be defective, and it was returned to the manufacturer who then supplied the project with a Geocel 000 stress captor in exchange. This captor consisted of a steel tube with three rubber sheaths surrounding it, forming an expandable single cell between the outside of the tube and the sheath, and it is considered to be a superior captor to the 00 captor. This captor was also defective and had to be returned to the manufacturer, and a decision to abandon the Undisturbed Site was made and further efforts to install a pressure sensor at this site were stopped.

Moisture and Density

Due to the suspected large amount of clay minerals present in the mineral assemblage of the Bearpaw Shale at the Test Site and the action of these clay minerals when exposed to increasing amounts of moisture, monitoring any change in the moisture content and density of the soil mass at the Cut Site was considered to be of the utmost importance. It had been theorized that increased moisture content was the primary cause of any volume change and insuing instability of the Bearpaw Shale in the previous failures. Because of the negative charge of the clay plate and the loose bonds between the clay layers, clay has a "thirst" for water and other polar molecules. Such polar molecules occur between the clay layers in a definite configuration, thus causing an increase in the basal spacing or repeated distance perpendicular to the layers.

This increase in basal spacing, if of large enough magnitude and spread over a wide enough area, can cause significant volume change in a soil mass. The increase in basal spacing can be of large enough magnitude as demonstrated by montmorillonite layers; the basal spacing of montmorillonite is 9.6 angstroms, the addition of one layer of water increases the spacing to 12.5 angstroms, and with two layers of oriented water the spacing increases to 15.5 angstroms for a 61% volume increase (2). White & Pilcher (1959, page 8) have shown that increased amount of water can be present, particularly in sodium montmorillonite. They have shown that it will take up 50 layers of water and possibly more. Fifty layers of oriented water molecules increases the basal spacing to 125 Å, an increase 1202% over the spacing of anhydrous montmorillonite. The increase in basal spacing is not the only cause of volume change that increased moisture content has been shown to have in clay. Clay platelets can actually be held in a bent position by the surface tension of small amounts of moisture. When these bent clay platelets are exposed to increased moisture content and reduced loading, as in construction of a roadway cut, the platelets can be released from their bent positions creating an expansive force. Terzaghi (1955) has shown that this bent platelet effect can be quite predominate in some expansive clays. It has also been demonstrated that monitoring the density of the shale in close correlation with the moisture content can be useful in evaluating the effect of increased internal air pressure. That is, if the soil mass initially contains a great number of interconnected air voids, all containing air at atmospheric pressure, and water enters the soil from all directions, as is the case in a new highway cut, it will compress the air in the voids thus increasing the pressure along the walls of the voids. If the surrounding structure is too weak to withstand this pressure the disruptive force may cause the soil mass to expand. An indication of the number of air voids could be obtained by preconstruction density measurements.

The subsurface moisture content and density of the soil masses at the test sites were monitored with a set of instruments manufactured by the Nuclear-Chicago Corporation and borrowed from the diameter of the access tube, the extra 1/16 inch is filled adequately when the walls of the drill hole relax around the tube after it is inserted. It is also felt that this overdrilling results in less disturbance of the soils density since drilling to the exact size of the tubing can result in some compaction as the tube is inserted, which would cause the measured density to be higher than the actual density of the mass. Because the access tube at the Cut Test Site would have to be installed in a 256 foot horizontal hole and the tubing is available only in random 20 foot lenths, installation of the tubing at the Cut Test Site was further complicated. In order to install the tubing, the first 236 feet of the hole was drilled using a 4½ inch drag bit with air as the circulatory media, then thoroughly cleaning the hole and casing it with 2 inch welded iron pipe. The hole was completed using a 1-11/16 inch fishtail bit and a special tapered collar (Fig. 12) which had been welded into the leading end of the casing. Upon completion of this final 20 feet, it was cleaned and the access tubing was pushed into place using a specially designed push collar (Figs. 12 & 13). To guard against the possibility of the sharp leading edge of the access tubing damaging the wall of the drill hole and to prevent any loose material from getting into the tubing, a plug (Fig. 12), which was also developed by the Colorado Highway Department, was installed in the end of the tube. This complicated task of completing the drill hole and inserting the access tubing was handled with exceptionally little

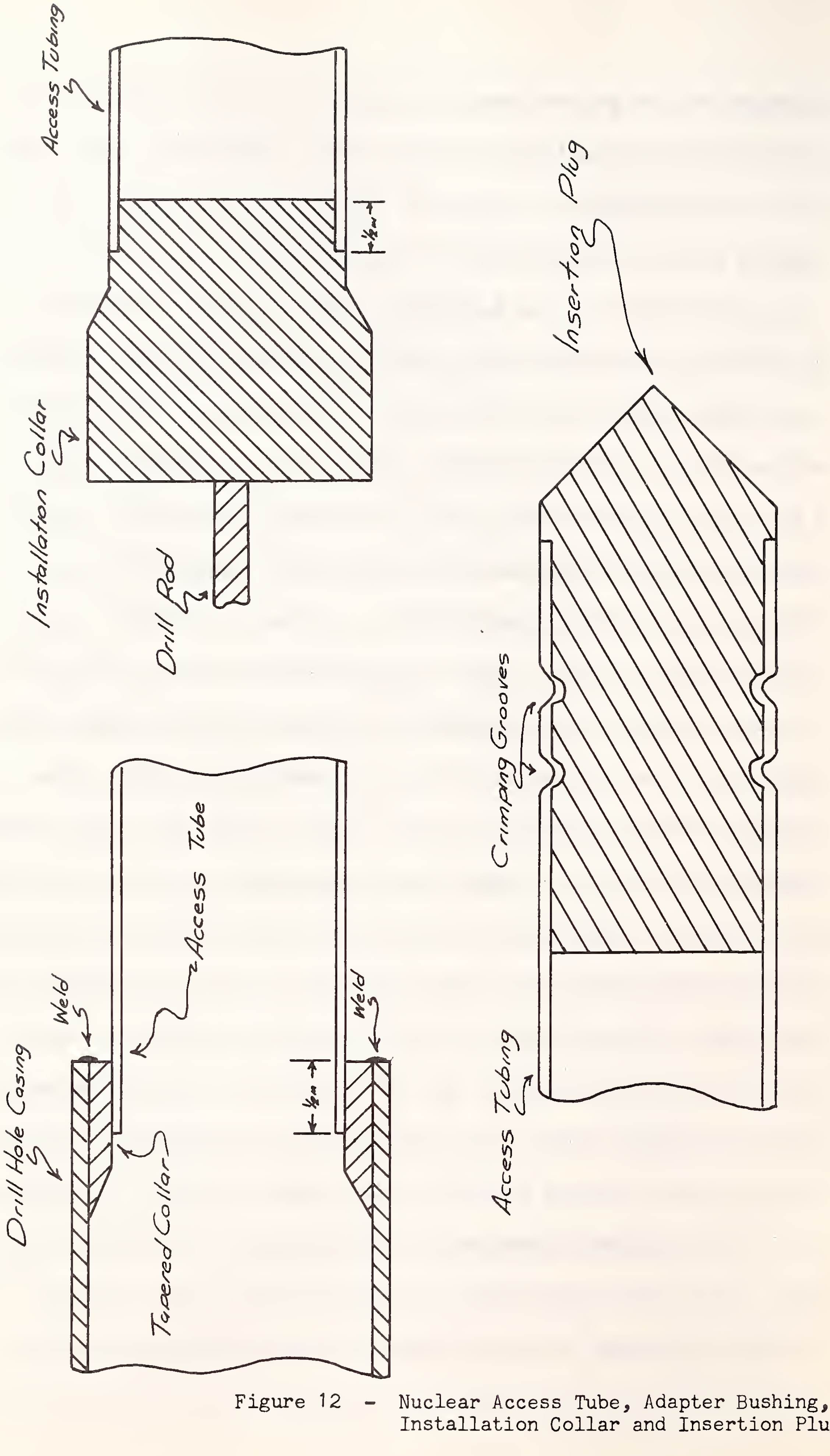

Figure 12 - Nuclear Access Tube, Adapter Bushing, Installation Collar and Insertion Plug.

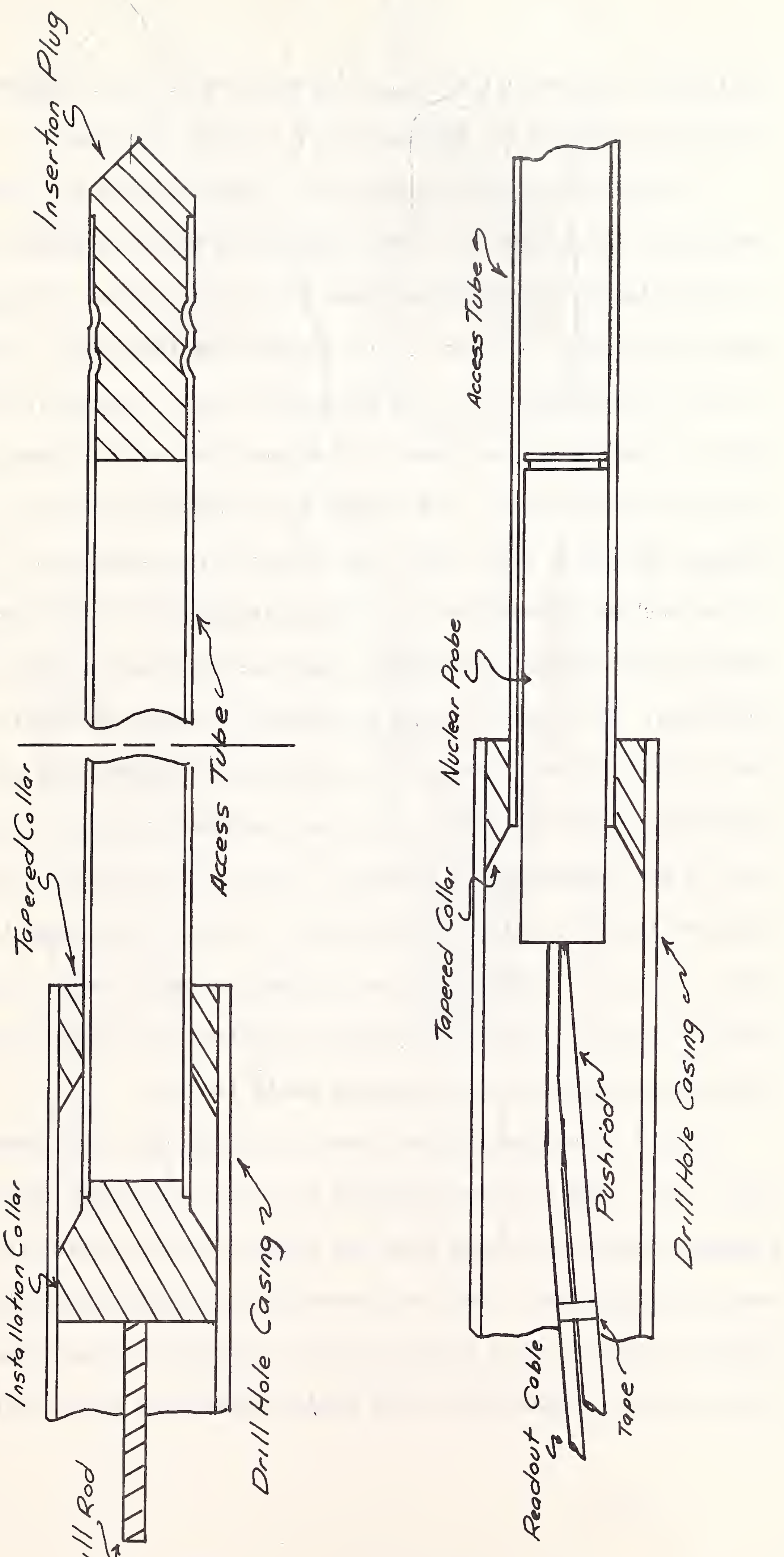

Figure 13 - Installation and Use of Access Tube

difficulty by the late Mr. C. W. Clement, Core Drill Supervisor, and the drill crews of the Montana State Highway Department.

The special tapered bushing at the junction of the two inch casing and the access tube was designed so that the probes could be installed by pushing them along the bottom of the casing, up the incline into position in the access tube (Fig. 13). In order to ease the extraction of the probes, the cable leading from the probe to the scalar was taped to the push rod as the probe was pushed into position. This helped to distribute the force of pulling the probe back, which could cause the separation of one of the pushrod connections. During this system's first test, the insertion of the moisture probe, numerous difficulties were encountered. While positioning the probe, it became difficult to push about half way through the access tube; rather than risk sticking the probe in the tube, it was decided to extract it; however, it was impossible to move it. The probe had become lodged 250 feet from the collar of the hole. During the attempt to extract the probe a pushrod connection pulled apart about 140 feet from the collar; continued efforts to extract the probe by pulling only on the instrument readout cable failed.

To aid in extracting the probe, a fishing tool was constructed (Fig. 14). This tool was designed to catch the broken end of the pushrod, thereby, allowing both the pushrod and the cable to be used for extraction. The tool consisted of an SAE $\frac{1}{2}$-inch tap, welded to the end of a 10-foot length of 3/8-inch, steel pipe, with a funnel-shaped, steel hood welded around the tap to allow

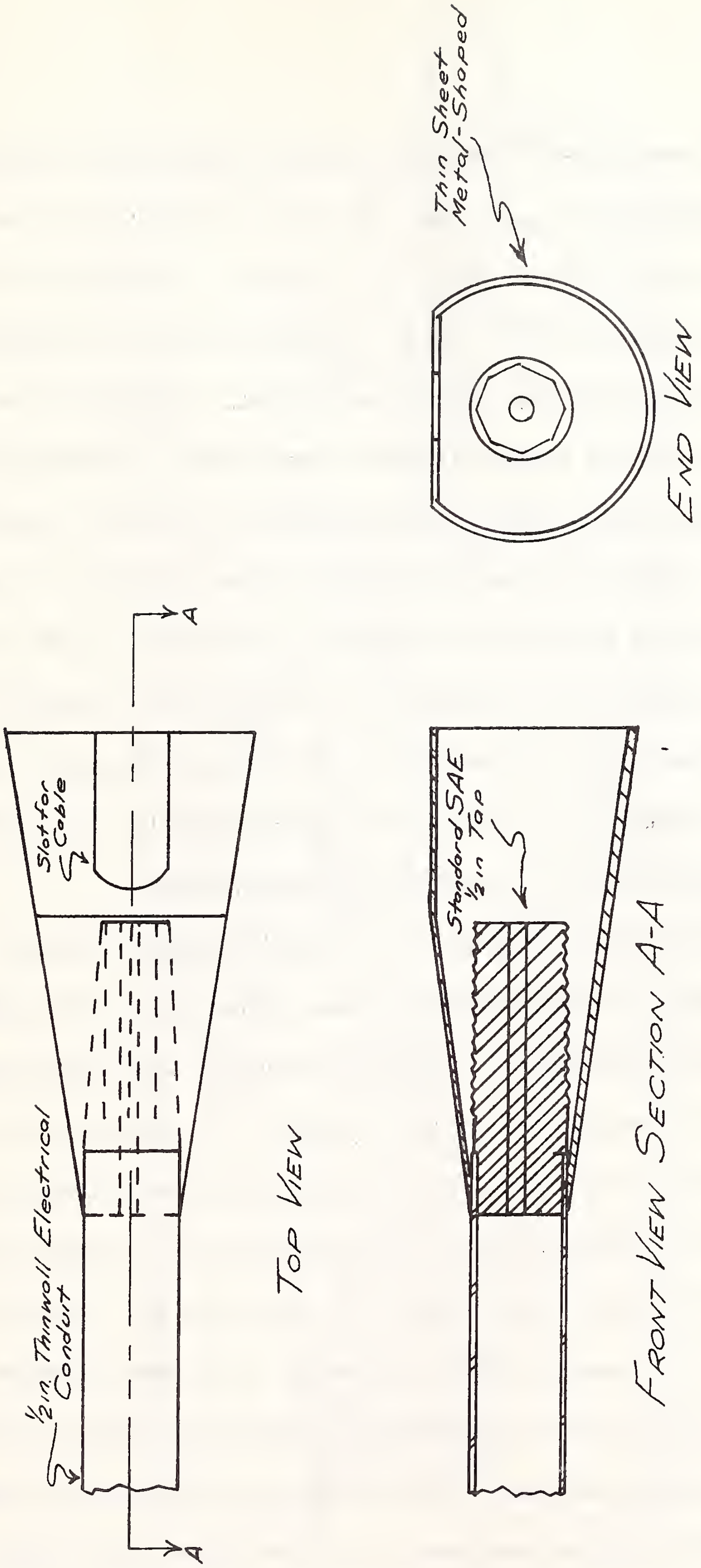

Figure 14 - Pushrod Fishing Tool

the broken conduit to slide onto the tap (Fig. 15). When the conduit was positioned on the tap, the entire fishing tool was turned to seat the tap into the end of the conduit, creating one rod. Attempts to catch the end of the tubing resulted in numerous failures, but the end of the conduit was finally taped,and two weeks after the probe had become lodged it was freed. However, during the two weeks interm water had penetrated the access tube and the probe case. The moisture in the probe case damaged the circuitry of the probe and necessitated returning the probe to the service center for repair and recalibration, causing still another delay and loss of moisture content data. This delay was made longer because the repair parts had to be custom made due to the fact that this model was no longer being manufactured.

To avoid similar damage to the density gauge, further trials were abandoned and another request was submitted to the highway officials for permission to locate a moisture and density monitoring station in the median of the highway. To emphasize the difficulties that the horizontal hole presented, several local officials were invited to Billings for a demonstration at the test site. For this demonstration a wood replica of the probe was used with rope to simulate the readout cable. Although this demonstration did go smoothly the officials recognized the potential damage to the probe and for possible personnel injury to anyone working with the probe. They,therefore, granted permission to locate the access tube in the median if precautions were used not to interfere with traffic flow

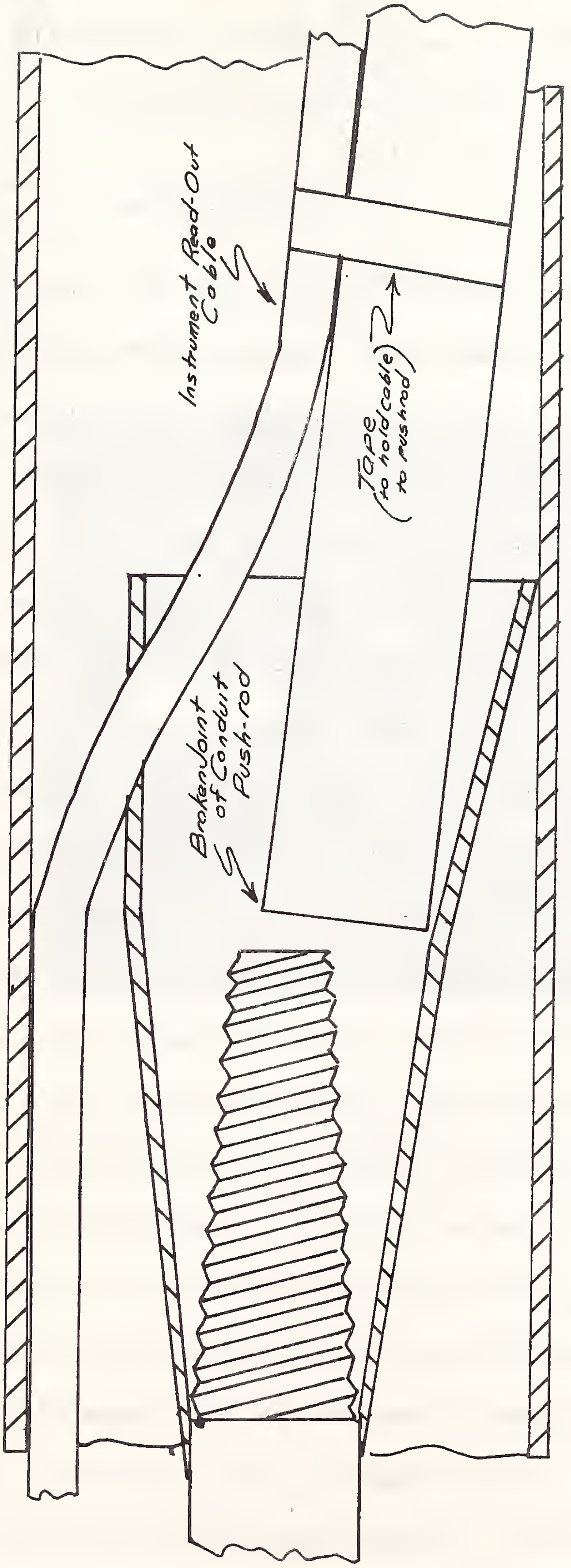
Instrument Read-Out Cable
Tape (to hold cable to pushrod)
Broken Joint of Conduit Push-rod

Figure 15 - Pushrod Fishing Tool, functional view

or safety. This was accomplished by covering the stations in the median at ground level as shown in Figure 16.

Conductivity

The conductivity of the soil mass was monitored in an attempt to relate any volume change caused by physio-chemical interparticular repulsion of the clay platelets. As explained in the discussion of the moisture and density, a clay platelet has a negative charge, and thereby a "thirst" for cations and polar molecules such as water. The union of a clay platelet with a water dipole or a cation forms an electrically neutral micelle. However, in some cases, the "thirst" of the clay is strong enough to attract both a water dipole and a cation, these attracted cations and the water in the micelles form double layers. Ladd (1960) has related the double layers to a correspond tendancy toward volume change. He explains that an interparticle repulsion, similar to that of electrostatic forces occurs in the clay mass. This occurs when two clay platelets are close enough for their double layers to interact. If the moisture content of the soil mass continues to increase and there is a continued attraction of the clay for the water dipole, the resulting increase in the number of water dipoles held by a clay platelet further enlarges it. This enlargement causes an increase in the interparticle repulsion by bringing the double layers close enough to cause interaction, thus expanding the soil mass (7). It was thought that by monitoring any changes in the soil's electrical conductivity and relating these changes

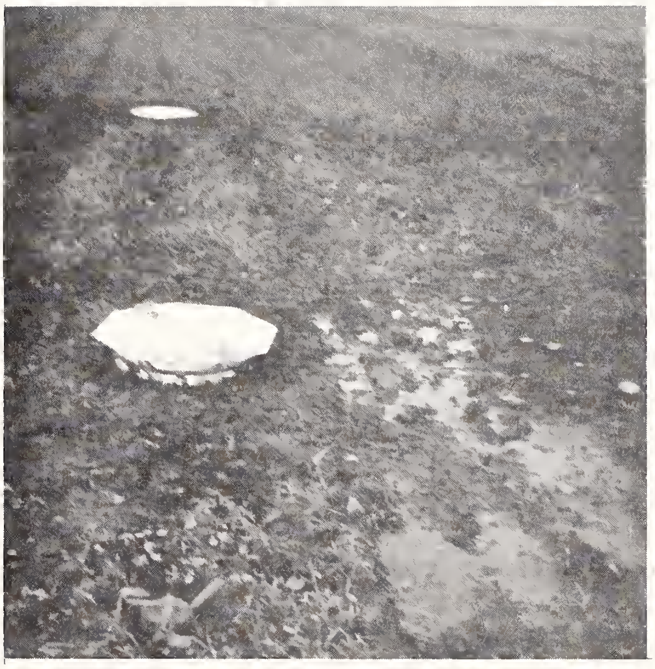

Figure 16 - Median Monitoring Stations

to any volume or pressure changes it would be possible to evaluate the effect of this physiochemical action. As the clay platelets attract the water dipole and/or the cations to form the electrically neutral micelles which interact, the electrical conductivity of the soil decreases.

The instrument used to monitor the soils conductivity was a Schlumberger 5FF40 induction well logging tool, which was leased to the project by Schlumberger Well Services. This induction logger operates on the principle of a mutual impedance bridge. A transmitter coil is fed with alternating current from an oscillator; this transmitting coil sets up an alternating field which produces eddy currents in the surrounding media, the number of which is directly proportional to the conductivity of the media. The eddy currents are detected as they set up an electromotive force in a receiver coil. This receiver coil is connected through an amplifier to a galvanometer where the amount of force induced is visually displayed. Because the amount of electromotive force is directly proportional to the number of eddy current, this force is directly proportional to the conductivity of the media.

The tool, when installed at the Instrument Test Site, functioned as expected; and to insure continued satisfactory operation prior to installation of the tool at the Cut Test Site, it was returned to the Schlumberger Service Center in Billings, Montana for service and adjustment. The length, weight, and delicate nature of the sonde prohibited its installation in a horizontal drill hole; therefore, it was installed in one of the two vertical holes. The hole used was drilled eleven inches in diameter to a depth of 27 feet with mud for circulation; this portion of the hole was then cased with eight-inch casing. The next 25 feet of the hole, to a depth of 52 feet, was drilled 5-5/8 inches in diameter using air for circulation to assure that the shale's natural condition would be altered as little as possible. The entire hole was then cased with four-inch, plastic pipe to avoid the presence of electrical conductors within the sphere of influence of the tool. After the sonde was lowered into position, a cap was welded over the hole to avoid any moisture from rain or snow entering the hole, and the readout cable was strung through a hole in the cap to the readout station (Fig. 6).

The only problem presented in using this equipment was the need for 60 cycle A.C. power. At the Instrumentation Test Site this problem was solved by having commercial A.C. power installed to the site; however, at the Cut Test Site it was not economically feasible to supply the site with such power because of the great distance to the nearest transmission line. Thus, it was necessary to use a power inverter and an automobile battery as the source of required power. This arrangement proved to be troublesome, particularly during the cold weather when the instrument had an increased demand for power, and the storage potential of the battery was reduced. In order to recharge the battery, it was necessary to transport it to Billings.

Axial Strain

Many investigators believe that the top portion of the shale swells to a greater extent than the lower portions. In order to investigate this hypothesis and to measure any strain produced in the soil the original plans for the Cut Site called for the use of an extensometer in the median of the roadway. However, when these plans were rejected by the highway officials, the use of such an extensometer could not be included in the revised plan because of the high cost of drilling the inclined hole from a location off the highway right-of-way, which would be required for use of this instrument. When the officials reconsidered and granted permission to locate a moisture and density monitoring station in the median, the importance of monitoring the axial strain of the shale was pointed out to the officials and permission to locate an extensometer in the median was also granted.

The instrument used to monitor the axial strain displacement was a Terrametrics Model 8CS-LK Multiple Point Borehole Extensometer with spring loaded watertight anchors (Figs. 17, 18 & 19) and mechanical readout equipment. The extensometer is designed to measure the axial strain component in an instrumented drill hole. As the drill hole is deformed axially, the distance between individual down-hole anchors and the instrument head changes. The distance changes measured by the extensometer are reduced to functions of anchor position and hole depth to yield the axial strain at each anchor.

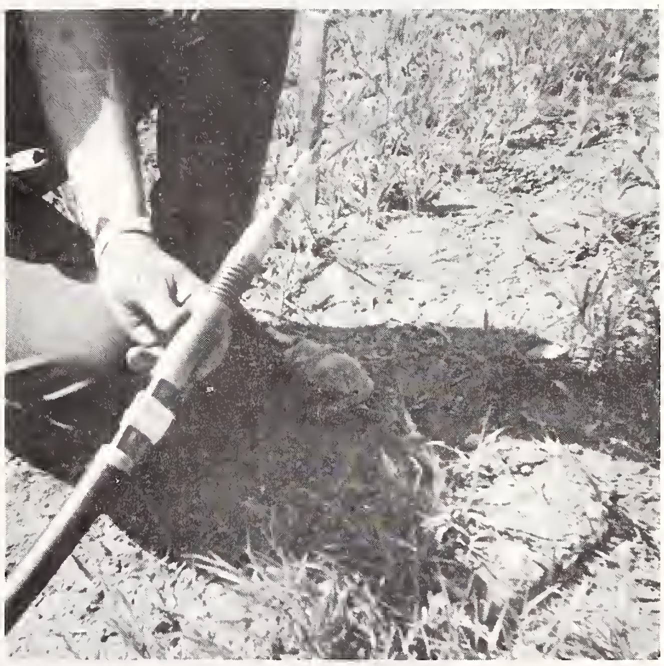

Figure 17 - SLW Type Anchor

Note Sensing Wires

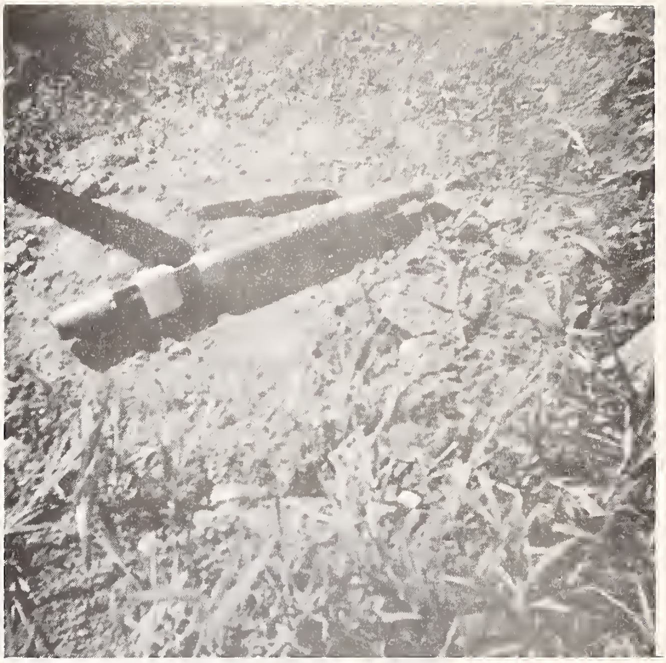

Figure 18 - SLW Type Anchors

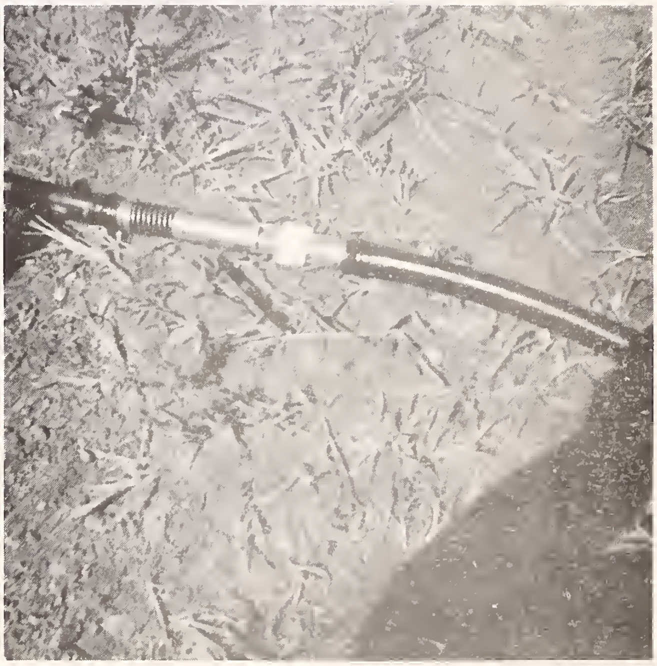

Figure 19 - SLW Anchor in Intermediate Position

The model used for this investigation detects the distance change with a dial indicator, which measures the position of sensing rods with respect to a gauging platform that is attached to the sensing head-collar anchor assembly (Fig. 20). Each sensing rod operates independantly and is attached by means of a steel wire to an anchor. The anchor is firmly attached to the surrounding soil and, therefore, must move with the soil. Any movement of the anchor causes the position of the sensing rod, with respect to the gauging platform, to change the same amount that the anchor's position has changed. This change in position is recorded with the dial gauge. The sensing rods are spring loaded, and when the anchor is attached the spring is depressed approximately half-way so that axial deformation of the borehole, in either the positive or negative sense, may be detected. This instrument was not tested at the Instrument Test Site because the anchors are non-retrievable, and the cost of such a trial would have been quite costly. Also, the equipment was quite simple in operation and had been thoroughly field tested several times by others and under conditions much worse than those expected at the Cut Test Site.

Eight anchors were used and were set six feet apart in a freshly drilled 3-inch, 50-foot, vertical drill hole in the median of the roadway. The instrument was assembled on the ground then lowered into the drill hole as a unit (Fig. 22). When it was properly positioned, each anchor was set and locked into position. The wires were then connected to the sensing head which had been anchored to the collar of the hole.

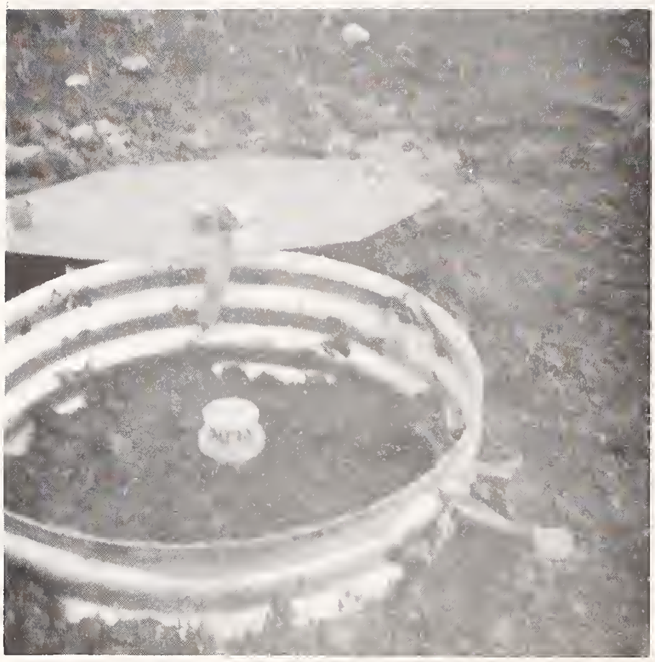

Figure 20 - Extensometer Collar Anchor Sensing Head & Gauging Platform

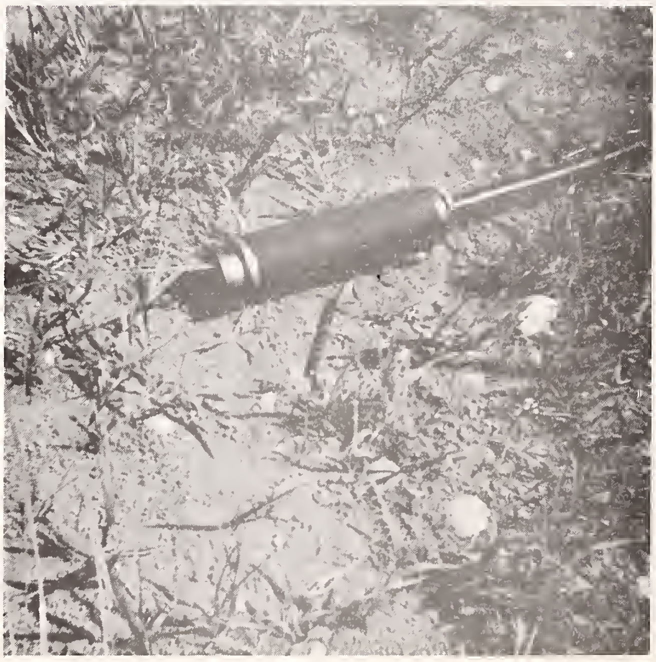

Figure 21 - Extensometer Collar Anchor

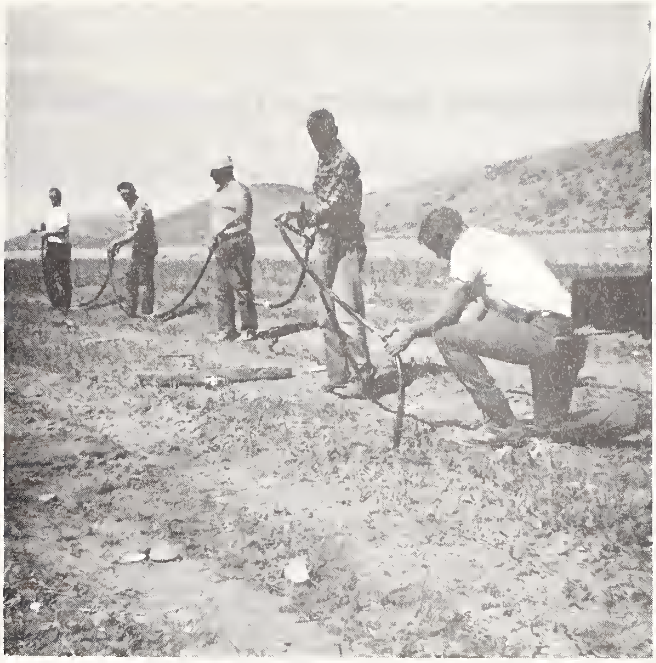

Figure 22 - Installing Extensometer

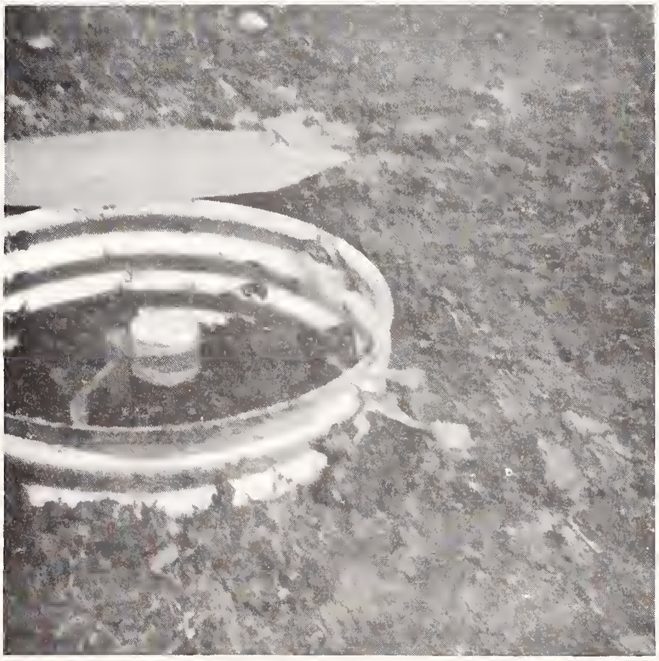

Figure 23 - Extensometer Sensing Head
with Protective Cover

This instrument performed as expected with only one small problem. The sensing head protective cap (Fig. 23) was tightened too tightly, and the entire sensing head assembly was twisted in an attempt to remove the cap. This created an error in the readings and necessitated establishing another set of base data, and relating it to the original, in order to correlate the data after the incident with that collected prior to the incident.

Horizontal Displacement

Because horizontal displacement of the soil mass had been evidenced in previous shale cut failure, an attempt to monitor horizontal displacement of the soil mass at the Cut Test Site was made. Preliminary instrumentation studies indicated that the cost of commercial equipment, available to monitor horizontal movement, was prohibitive for this study. This study did, however, uncover the possibility of constructing an instrument to monitor the horizontal displacement. Further investigation of this possibility resulted in the construction of a borehole inclinometer. Actually two inclinometers, each employing different principles, were constructed.

The first model constructed was modeled after the Swedish Geotechnical Institute (SGI) contact Pendulum Inclinometer. This inclinometer, which seemed at first to completely satisfy the requirements of this study, was developed by T. Kallstenius & Dr. W. Bergau of the Swedish Geotechnical Institute for long term use and was designed to be operated by a non-specialist. In principle this device is mechanical; the position of a pendulum, which is hinged on ball bearings and always assumes a vertical position, is determined with respect to the position of the instrument case which assumes the inclination of the drill hole. The position of the pendulum is determined with a micrometer screw, which, when in contact with the pendulum, completes an electrical circuit and generates a signal. This screw is turned by twisting a knob located above the ground (Fig. 24). By counting the number of rotations of the knob necessary to complete the circuit and comparing this number to the number of turns required to make contact when the instrument is held vertically, the inclination of the borehole can be determined. The pendulum and contacts are immersed in oil which protects the contacts against corrosion and offers a dampening effect for the pendulum, insuring good contact without noticeable deflection of the pendulum. This instrument was constructed and tested in the laboratory and at the Instrument Test Site.

A problem was encountered in adequately anchoring the instrument into position in the tubing used as casing for the test borehole. Originally a leaf spring was fastened to the instrument case to hold it into place but difficulty in adequately fastening the spring to the case resulted in abandoning this method and replacing it with an inflatable rubber bladder. This rubber bladder was placed around the instrument case and inflated to hold the instrument firmly into position. Although this model functioned quite well at the Instrument Test Site, it was decided to construct another model based on the SGI strain gauge inclinometer. The

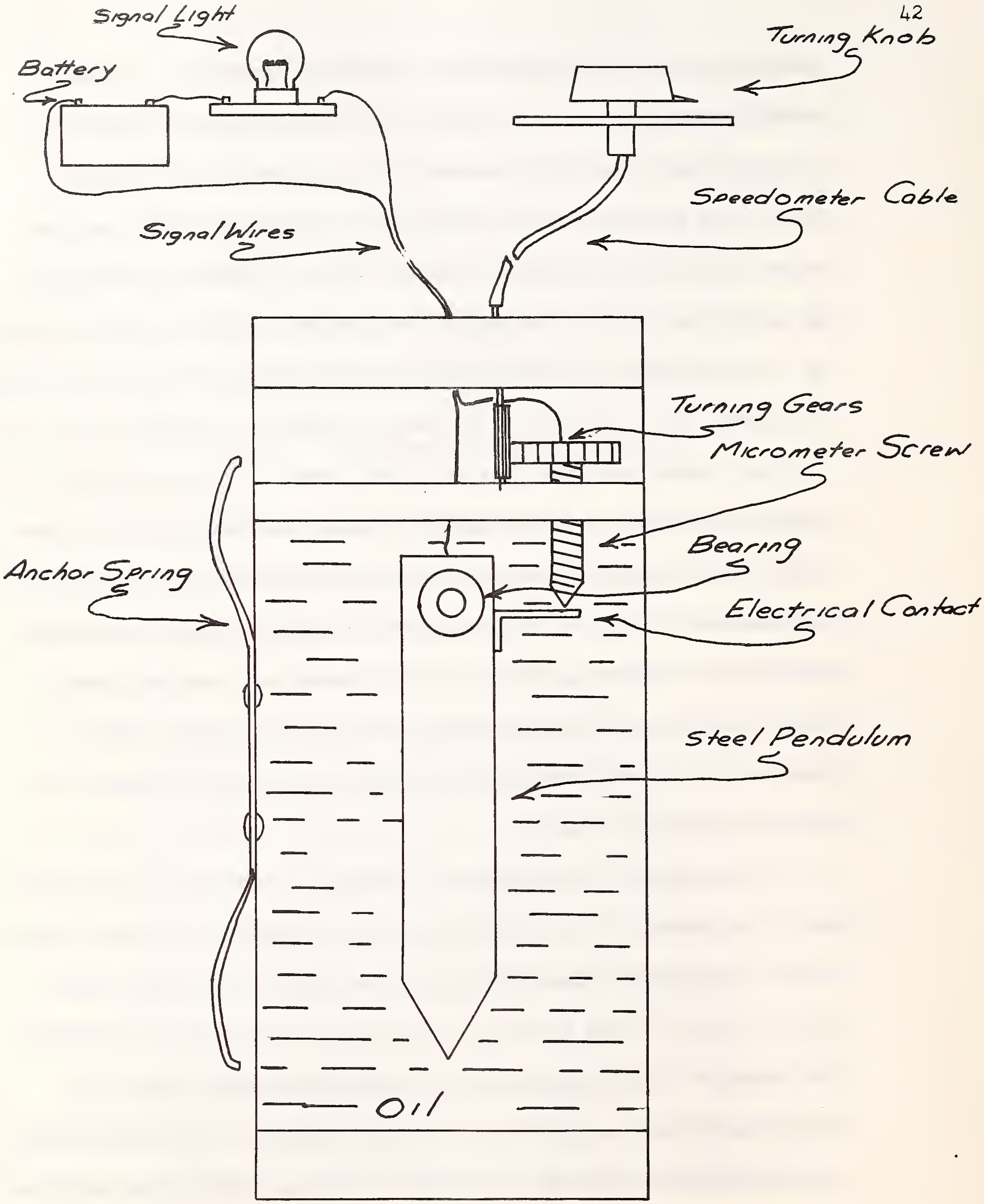

Figure 24 - Contact Pendulum Inclinometer

new model had an increased range and eliminated the mechanical readout which could have impared the accuracy of the instrument during cold weather.

The strain gauge inclinometer which is completely electrical in its readout was also developed by Kallstenius and Bergau. The basic principle of operation of this model is the measurement of the strain in a leaf spring as the leaf spring is stressed by a weight attempting to hang vertical. One end of the leaf spring is firmly attached to the instrument case and the other end is fastened to a weight which creates a cantilever effect in the leaf spring when the instrument case is inclined from vertical (Fig. 25). Calibration of the strain produced in the spring with known angles of inclination make it possible to determine the angle of inclination of a borehole in which this instrument has been fastened. This instrument was also held in position with an inflatable rubber bladder. Time schedule for the investigation did not allow testing of this model at the Instrument Test Site, and it was, therefore, installed directly at the Cut Test Site.

A set of two strain gauge inclinometers were used to monitor the horizontal movement. The two instruments were rigidly fastened together oriented in such a position to measure the movement in any direction. The lines of action of these two instruments were oriented 90° apart, and it was anticipated that it would be possible to detect the direction and magnitude of any horizontal movement rather than movement in just one direction as would be the case if just one instrument was used.

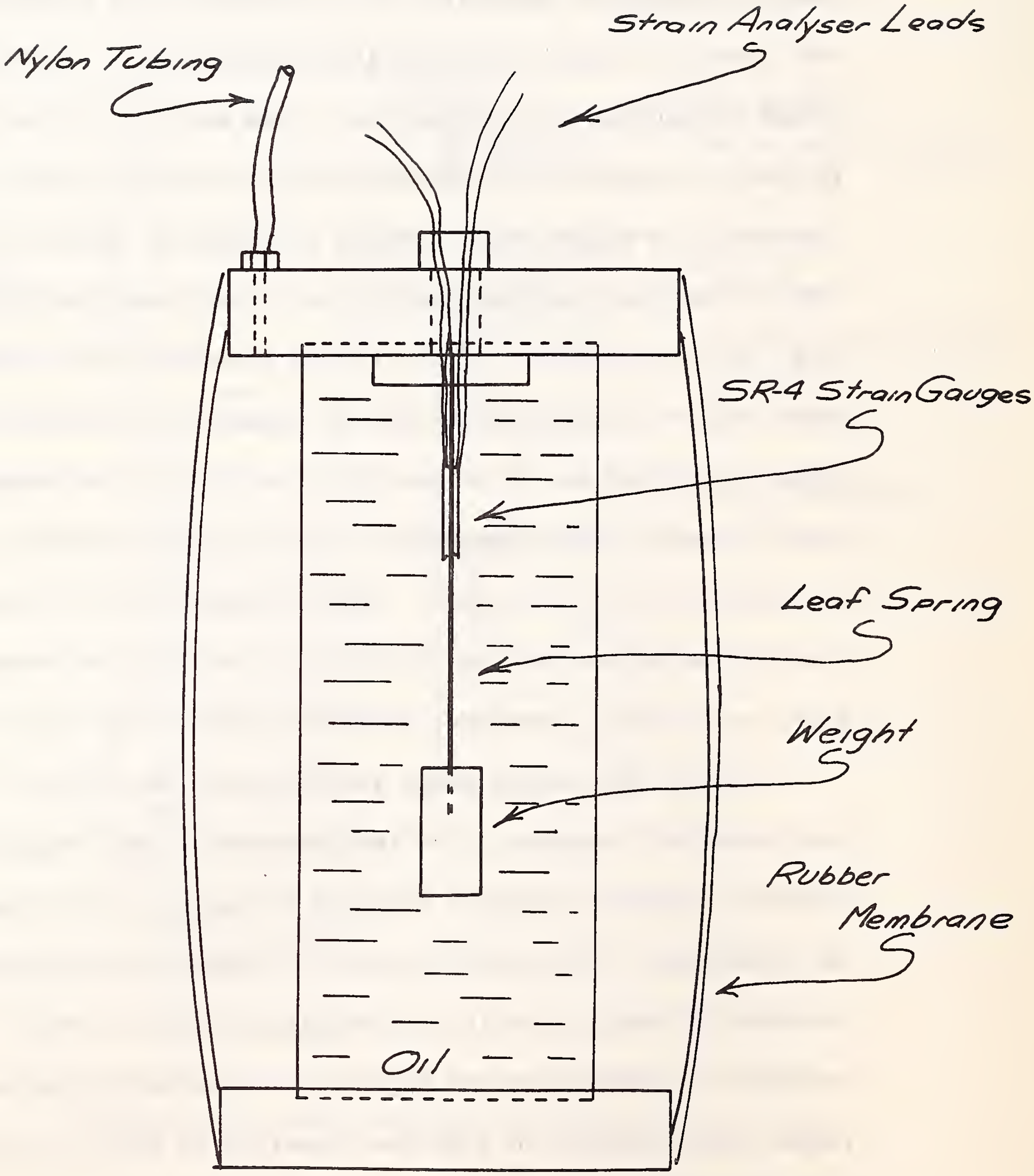

Figure 25 - Strain Gauge Inclinometer

Another method for determining movement in any direction, and its magnitude, was developed by Kallstenius and Bergau during their investigations. A single inclinometer is slowly rotated one complete revolution inside the drill hole and the orientation of the line of action of the instrument causing the maximum strains is noted. This orientation is the direction of the maximum movement; because during one turn the spring will deflect to a maximum in one direction and to a maximum in the other direction, it is possible to determine the direction of movement quite accurately. This measurement method also eliminates a number of sources of systematic error associated with strain gauges; zero drift, creep in the bonds, and temperature difference between the measuring bridge and instrument. The inclination of the borehole is determined by calibrating the difference between the two maximums with known inclination. It was impossible to use this measurement method for this investigation because of the time required to perfect a system to rotate the inclinometer.

The set of instruments used at the Cut Site were installed in a 42 foot horizontal hole on the knob of the hill (Fig. 5). The hole was drilled 5-5/8 inches in diameter and cased with three-inch plastic pipe. Prior to installation of the instrument, the void between the walls of the drill hole and the casing was backfilled with a mixture of fine sand and clay. This backfill method was used to assure that the casing would be held tightly to the walls of the drill hole insuring detection of any horizontal movement of the shale mass, while eliminating any inaccuracies caused by the casing moving in the drill hole.

Numerous problems were encountered during the use of this set of instruments. It was noted shortly after installation that one strain gauge on each instrument was not functioning properly; it was thought that these two were not adequately bonded to the leaf spring. Because it was possible to operate the instrument at a reduced accuracy with only one gauge working actively, the instruments were not repaired due to the possibility of losing considerable amounts of data. Difficulty was also experienced in maintaining the air pressure necessary to hold the inclinometer in place. This problem was solved by periodically checking the pressure and increasing it with a hand airpump if inadequate. During the very cold portion of the second winter the hole in which the inclinometer was positioned became plugged with ice, damaging the inclinometer case and necessitating the removal of the instruments for repair. Repair of these instruments would have taken considerable time and termination date of the study was approaching; therefore, the use of these instruments was discontinued.

Temperature

Most investigators believe that the amount of swell a soil mass is a function of the increases in temperature of the mass. It has been shown that the interparticle force and the pore-water pressure are both increased with an increase in temperature (9). It has also been demonstrated that a temperature increase of ten to fifteen degrees Fahrenheit can cause a soil to increase in volume by 0.5% due to thermal expansion. An increase in the temperature of the shale was expected as the overburden was removed by the construction of the cut; the effect and size of this increase in temperature were of primary concern.

In order to gain the true effect that any increase in temperature may have on the stability of the shale mass, the original plans for the Cut Test Site included the measurement of a temperature gradient from the preconstruction ground level to about twenty feet below the finished subgrade. By correlation of this temperature data with the extensometer data and information on the amount of overburden removed daily, it was anticipated that information relative to the immediate effects of the increased temperature could be obtained. The long range effect could be obtained by continued monitoring of the temperature after construction was completed and then correlating this data with the other data obtained by the various sensors. However, when the original plans were to be revised, it was impossible, with the revised plans, to gain any information about the immediate effect of the temperature increase since some of the sensors would be located under a large volume of overburden and others would be located under the finished roadway. The revised plans did provide for measuring the temperature gradient of a horizontal hole, from its collar to its terminus, in order to monitor the long range effect of the increased temperature and to obtain an approximate value for the increase.

The temperature sensors used at the Cut Test Site and at the Undisturbed Site were YSI-44003 thermistors. Thermistors were not tested at the Instrument Test Site because it was originally thought that a continuous record of the temperature would be necessary. Therefore, for trial purposes at the Instrument Test Site, two Fisher-Porter Continuous Temperature Recorders were used. This trial indicated that these would be inadequate for use at the Cut Test Site because of the poor quality of record produced, the difficulty in interpreting the record, and the large size of both the probe and recorder housing. This trial also demonstrated that a continuous record of the temperature was not necessary. When it was discovered that the recorder would not work at the Cut Test Site, a number of other temperature sensors were investigated and thermistors were chosen. It was felt that trial of the thermistors at the Instrument Test Site was not necessary because the research had shown that this type of sensor had performed well in similar applications.

To protect the thermistor and to make their installation easier, each thermistor was encased in a short length of 1/8-inch, nylon, pressure tubing and surrounded with Duco Cement forming a larger unit and protecting the thermistor without affecting the operation of the sensor. At the Cut Test Site these pieces of nylon tubing containing the thermistors were taped to one foot lengths of ½-inch, wood doweling and positioned in the horizontal hole by pushing the dowel to its desired position with a pushrod. To avoid confusion during readout, the leads of the thermistors were connected to a multi-position switch. Readout was accomplished by moving the position of the switch and recording the corresponding resistance. These resistances, when correlated to a calibration curve supplied by the thermistor manufacturer, produced the soil temperature in degrees Centigrade. At the Undisturbed Site the nylon tubes were taped to carriage bolts and suspended at various depths in the vertical drill holes by tieing the lead to the collar of the hole. Because there was not a readout station at this site, a multiposition switch could not be used, and it was necessary to connect the ohmmeter with alligator clips to each set of leads to record the corresponding resistances.

Both arrangements worked quite well; the only operational problems encountered were at the Undisturbed Site. The ground water present in the drill hole used to monitor the temperature was so corrosive that the small leads of the thermistors were damaged, thereby, yielding poor data and, eventually, ruining the affected units. The units which replaced those which were damaged were dipped in molten paraffin to protect them from the corrosive action of the water. The only difficulty at the Cut Test Site was encountered during the installation operation; for some unknown reason, it was impossible to push a thermistor any further than 226 feet from the collar of the hole even though the hole had been cased for 240 feet. Because a thermistor could not be positioned under the roadway this difficulty resulted in the loss of the desired data on the effect of the volume of overburden on the temperature of the shale.

GROUND WATER

The most distinguishing difference between the cut investigated by this study and those investigated by Colorado and Wyoming State Highway Department studies is the presence of ground water in the cut. The water was first noticed during the construction and was considered by the highway department officials to be run-off water from the irrigated bench land south of the cut. When excavation of the cut was completed it was noticed that water was flowing from the south cut face as shown in Figures 26 and 27. Closer investigation indicated that the ground water was flowing in a horizon of the shale which appeared to be related to a hard layer of shale (Figs. 28 & 29). The continued flow of the ground water necessitated installation of French Drains under the roadway to drain the water from the cut; the position of these French Drains are indicated in Figure 3. When the holes were drilled in the median for the extensometer and nuclear access tube, ground water with a static level below the hard shale was encountered indicating that the shale mass below this hard layer was also exposed to the ground water.

The presence of this ground water in the median and the continued flow of water from the cut face indicated that the shale mass exposed by the cut was becoming saturated with ground water. To determine the effect that this water could have on the swelling characteristics of the shale, samples of the water in the median flowing from the cut face and in the Undisturbed Site were collected and sent to the Montana Bureau of Mines and Geology for

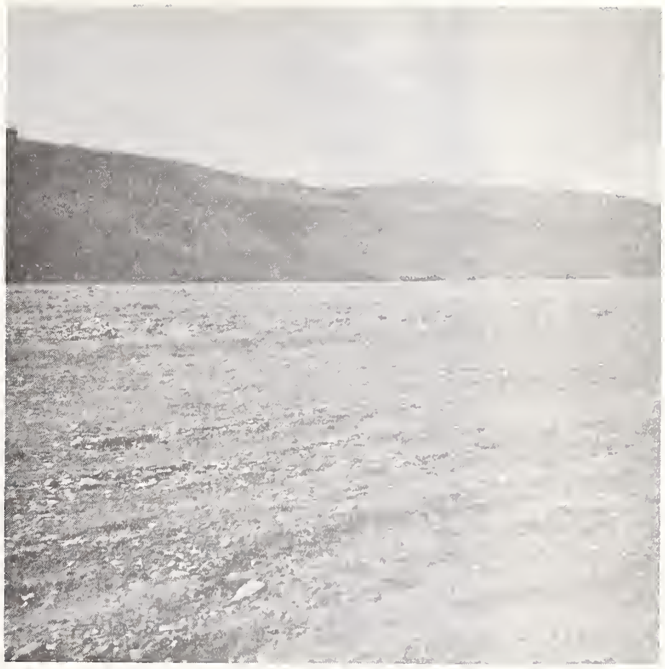

Figure 26 - Ground Water Flow from South Cut Face

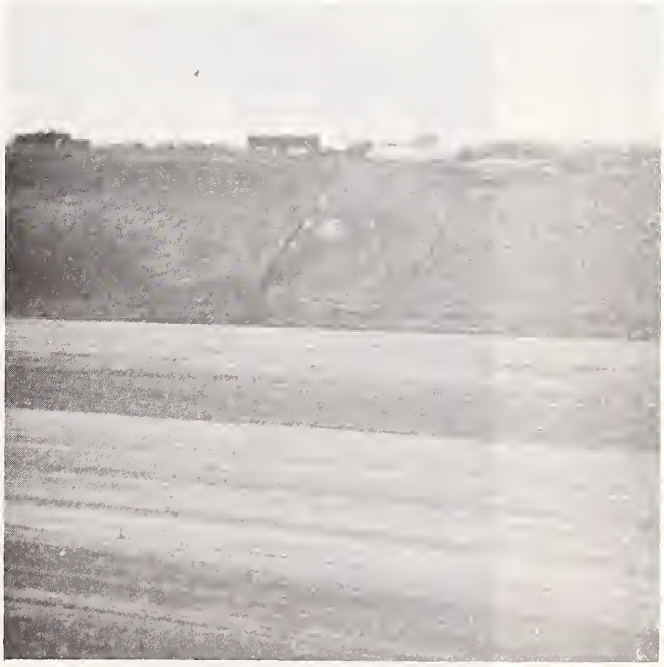

Figure 27 - Ground Water Flow from South Cut Face

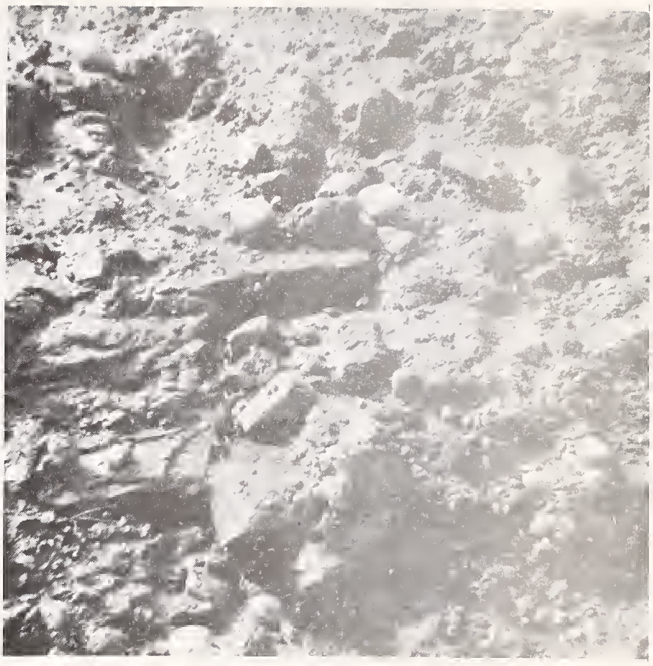

Figure 28 - Ground Water Flow along Hard Shale Layer

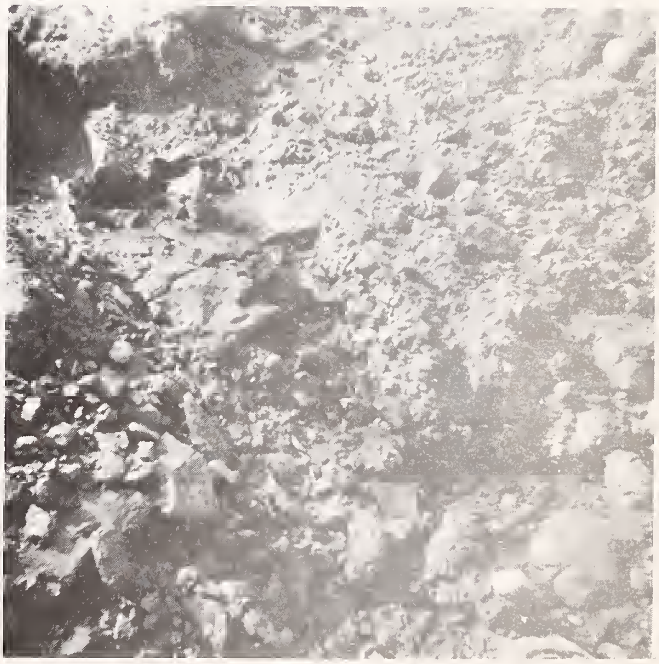

Figure 29 - Ground Water Flowing from South Cut Face along Hard Shale Layer

analysis. The analysis, Table I, gave evidence of dissolved cations at all sites, with a particularily large quantity evident in the Undisturbed Site. The presence of these dissolved cations increased the possibility of swell due to the formation of double layers in the clay's structure and the insuing interparticular repulsion as explained previously with the discussion of conductivity. While the presence of the ground water in the median at the Cut Test Site seems to renew the usefulness of the Undisturbed Site, the wide differences in the water analysis data indicates that the shale at the two sites are truly not exposed to the same conditions.

In order to observe any variation in the ground water level and the effect of these variations on the stability of the cut, the static level of the ground water in the median was monitored, by measuring the level in a 50-foot, 2-inch drill hole cased with perforated plastic pipe.

TABLE I

LOCATION	SAMPLE DEPTH	CALCIUM (mg/l)	MAGNESIUM (mg/l)	SODIUM (mg/l)
Cut Face	—	54	36.1	75.0
Median	8.8	54	20.2	175.0
Undisturbed	18.1	104	48.8	300.0

	BICARBONATE (mg/l)	CARBONATE (mg/l)	SULFATE (mg/l)	CHLORIDE (mg/l)
Cut Face	289	0	147	17.0
Median	291	0	351	10.9
Undisturbed	423	0	714	2.8

	DISSOLVED SOLIDS (mg/l)	CARBONATE HARDNESS (mg/l)	NONCARBONATE HARDNESS (mg/l)	TOTAL ALKALINITY as $CaCO_3$ (mg/l)
Cut Face	618	236	48	236
Median	902	218	0	238
Undisturbed	1593	347	113	347

	SODIUM ABSORPTION RATIO	SPECIFIC CONDUCTANCE at 25°C (micromhos)	PH
Cut Face	1	789	7.41
Median	5	1208	7.58
Undisturbed	6	2100	7.68

PROCEDURE AND RESULTS

Data Gathering Procedure

Data from each sensor was collected by a student of Eastern Montana College, located in Billings, employed by the project. This data was collected on a daily basis during the first portion of the investigation; however, the daily change in the variables was not of enough significance to warrant the cost of daily collection and during the latter portion of the investigation data was collected on alternate days. The sensors at both the Cut Site and Undisturbed Site were read during the late afternoon hours in order to eliminate any effect that the time of collection could have on the results.

The raw data collected in the field was relayed to Butte for reduction to final form, storage and correlation. This reduction was accomplished with the aid of a computor; programs were written to correlate the raw data collected from the sensors to the calibration factors for the sensor and punch the reduced data on a computor card making storage, handling, and recall of the data no problem. The data included in the appendix of this report is a listing of these cards. The correlation of the data was done graphically using plastic drafting film to allow overlaying the graphs for comparison. Brunning prints of those graphs considered important to the results of this study are included with this report as Plates I & II. To make correlation of the data and plotting of the graphs easier, the calendar days from the date of the first pressure reading to the termination of data collection were converted to project days.

Results

The results of this investigation yielded very little information as to the causes of instability in highway cuts which unload Bearpaw Shale because the cut investigated showed little evidence of instability. However, a great deal of knowledge was gained about the instrumentation and procedures for future investigations of this type. Also, the data collected offers a fine base for comparison with the data from future shale cut investigations, particularly if the cut demonstrates instability. Therefore, to aid any future investigators, all of the useful data collected during this investigation is included in the Appendix of this report. A number of suggestions for future investigations are also advanced.

The pressure trend line, Plate I, indicates the cut is stable by the slow decline in soil pressure. If the cut was unstable, there would be some form of increasing pressure rather than declining pressure. The steep decline in pressure evident on the left-hand side of the trend line is caused by the excavation of the cut; and the sudden decline beginning at project day 90 and continuing to project day 107 is due to completion of the excavation directly over the bladder. The sudden increase in pressure beginning at day 107 and ending at day 121 is thought to be due to a combination of compaction of the roadbed subbase and adjustment of the shale mass to the reduced pressure. It would have been advantageous for the investigation of this phenomena if the density probes had been in service at that time so that any corresponding density changes could have been correlated with the pressure data. However as previously mentioned, due to delays and problems these instruments were not available.

Correlation of the pressure trend line with the estimated excavation trend line (Plate II) further supports the thought that this marked reduction in pressure and corresponding increases are due to action of the contractor directly over the bladder. The estimates of soil weight reduction as present in Table II and plotted on Plate II were obtained by estimating the amount of excavation done directly over the pressure cell as a fraction of the total daily excavation which was obtained from the highway department.

The density data, (Appendix B) from the time of the installation of these probes, project day 256, to the termination of the investigation indicates no change in the density other than normal variations associated with the use of nuclear probes. There is clearly no trend of increasing or decreasing density. The density at the different measured depths does, however, demonstrate a pattern; the density at the five foot depth is consistantly lower than those at the three and seven foot depths. This phenomena is considered to be caused by disruption of the soils in-place density to about the five foot depth through excavation of the cut and the reduced effectiveness of the compaction of the subbase at the five foot depth as compared to the three foot depth. This possibility is strengthened by the fact that the density at the seven foot depth is consistantly approximately five pounds per cubic foot greater than the density at the three foot depth.

TABLE II

APPROXIMATE REDUCTION IN SOIL PRESSURE OVER PRESSURE CELL

MONTH	DAY	YEAR	DAYS	TOTAL FEET REDUCTION	TOTAL WEIGHT REDUCTION	
12	8	67	0	1	95 lbs/ft^2	*
12	11	67	3	6	570	
12	15	67	7	9	855	
12	18	67	10	11	1045	
12	22	67	14	12	1140	**
3	6	68	88	13	1250	***
3	7	68	89	14	1360	
3	11	68	93	16	1580	
3	13	68	95	17	1690	
3	14	68	96	18	1800	
3	15	68	97	19	1910	
3	18	68	100	21	2130	
3	22	68	104	22	2240	
4	1	68	113	24	2420	
4	3	68	115	26	2680	
4	4	68	116	27	2790	

* Gravel at 95 lbs/ft^3

** Gravel excavation completed

*** Shale at 110 lbs/ft^3

The moisture content (Appendix B) also demonstrates no trend of increase or decrease. The moisture content remained about twelve pounds per cubic foot throughout the interval that it was monitored. An increase in the moisture content with increasing depth of measurement is, however, evident. This increase with depth was expected because of the ground water present in the median.

The conductivity data collected (Appendix C) indicates only a slight increase in the conductivity of the shale mass, 0.60 centimhos. This increase is probably due to condensation in the casing of the drill hole containing the sensor rather than a true increase in the conductivity of the surrounding soil mass. Also because of its small magnitude, it is considered to be insignificant.

The axial strain data, corrected for the error caused by the twisting of the sensing head (Appendix D) appears to demonstrate a trend of increasing axial strain. However, closer examination indicates that increase in extensometer readings is equal to approximately the same amount for all eight anchors, if the obvious instability of the first day's readings of the anchor at 7, 19, 25, 31, 43 and 49 feet is disregarded as the base reading for those anchors and the more reliable readings of the next reading day, project day 255, are used as a base. The difference between the base readings and the reading of the final project day, 533, range between 0.023 and 0.026 inches for the different anchors. Because the amount of increase shown by each anchor is equal to approximately the same value, it is thought that the clay in the median may have demonstrated some swell in the first seven feet. However, the amount of the apparent swell, 0.025 inches, is so small that it is considered insignificant as an indication of instability of the cut. It is also possible that this difference is due to a systematic error such as slight movement of the collar anchor or sensing head.

Because of the large number of error sources in the inclinometers used by this study, the data collected from them can not be intelligently considered to be of any value, and therefore is completely disregarded in the results. Disregarding this data appears to be of no significance since the area appeared to be stable and there were no indications of horizontal movement.

The temperature data collected at the Cut Test Site (Appendix E) indicates a slight increase in temperature as the thermistors approach the cut excavation. The temperature also appears to demonstrate slight increase in seasonal fluctuations closer to the cut. The thermistor placed at 48 feet from the collar, under a large volume of overburden indicates a temperature range of 9.03 to 9.71 degrees Centigrade, while the thermistor positioned 226 feet from the collar, under a smaller volume of overburden and closer to the cut had a range of 10.84 to 11.88 degrees Centigrade. This increase in range and mean temperature does seem to indicate that the cut does have an effect of increasing the temperature of the soil mass. This increase could, if of large enough magnitude, cause the clay minerals present to swell, as previously explained. The large daily and seasonal variations of the data for the temperature at the collar of the hole and on the surface was expected because these sensors were more directly exposed to the weather conditions. The variations noted for the thermistors at 218 and 210 feet toward the end of the investigation are disregarded because it is felt that these are due to malfunction of these thermistors.

The temperature data from the Undisturbed Site is not included or discussed because the site was abandoned and any observation made there is considered to have no effect on the investigation.

The ground water level at the Cut Test Site is the only variable monitored during this investigation that gave any indication that the roadway might fail. The data collected indicated a steady trend of rising ground water level during the period in which it was monitored, August through May. This steady increase and continued flow of ground water from the south face of the cut indicates that this cut may have intercepted a ground water flow pattern. This interception could cause great difficulty if the water table continues to rise to sufficient height to break down the subbase or if the water began to flow into the fill east of the investigated cut, imparing its stability.

This presence of the ground water may be the reason that this cut was stable. A review of the history of roadway cut failures occuring in the Bearpaw Shale, as presented in the reports of the Wyoming and Colorado Highway Departments, indicates that in all cases these failures occured in dry regions where the clay minerals present had not been exposed to free water until the construction of the cut. The presence of the large volume of free water at the cut studied by this investigation establishes the possibility that clay minerals present may have previously reacted to the presence of this water and therefore were in a stable state, having satisfied their "thirst."

Possible Sources of Error

As in any observation, there are a number of possible sources of error associated with this investigation. Generally speaking, the sources of error present are of the chance or random variety -- errors produced by the large number of unpredictable and unknown variations in the situation at the test site. These errors resulted from small judgement errors, such as estimating beyond the smallest scale division, unpredictable fluctuation in temperature, or variations in the power source voltage. However, after careful investigation of the data, it is felt that these sources did not significantly affect the results and are mentioned only as a word of caution for other investigators.

In this investigation the systematic error sources, sources associated with a particular instrument or technique of measurement (14) are more important than the random error sources. Because there are no general principles for avoiding systematic errors, only an investigator's experience (14). The systematic error sources associated with each sensor are discussed below:

PRESSURE

Because of the mismatch in modulus of deformation between the soil and the pressure cell body, it was impossible to determine the true stress of the soil at the Cut Test Site, and the data collected can only be used to determine any changes in the soil stress. This mismatch or inclusion effect which also restricts the accuracy in measuring any stress changes at the point of inclusion, is due to two factors:

1. The cell does not behave like the soil it replaces, and
2. The installation in the undisturbed soil requires remodeling the soil in the vicinity of the gauge which causes an additional mismatch of conditions (3).

The cell does not behave like the soil because its stress-strain characteristics are different than those of the surrounding soil. This difference will cause a redistribution of the stress around the gauge causing too high a reading if the soil is less stiff than the gauge, or too low a reading if the soil is stiffer (3). The effect of this mismatch of the modulus of deformation is further complicated for a balloon type pressure cell, such as the one used in this investigation, because the stiffness of the cell changes as a function of the soil pressure. Therefore, the data collected by the Geocell 00 pressure captor is subject to varying degrees of systematic error. Because the original purpose of the pressure sensor was to detect any pattern of change in the soil pressure caused by the construction activity rather than to measure the free field stress of the soil mass or accurately determine the stress change, the error caused by this inclusion effect is considered to be of limited importance to the data presented in Appendix A.

Because it is recommended by this study that any future investigations of this nature attempt to measure the true soil stress, it is worthy to note that little success has been attained in matching the modulus of deformation of the gauge and the soil (3) and the fact that the inclusion error is also directly proportionable to the thickness-to-diameter ratio of the pressure cell (8 and 10). The only solutions appear to be to provide calibration for the error or to minimize the effects by proper geometric design of the pressure sensor. Very little work toward a calibration has been done, however, a procedure has been developed by Spokane Mining Research Laboratory of the U. S. Bureau of Mines, and is discussed in U. S. Bureau of Mines Report of Investigation 6893, "Flexible Liners for Underground Support." The proper geometric design of a pressure sensor to eliminate this inclusion effect is also discussed in the same report.

MOISTURE AND DENSITY

Two possible sources of systematic error in the moisture and density data were noted previously in the discussion of these probes -- selection of proper access tube and adequate installation of the tube to avoid air gaps. These possible error sources were avoided in this investigation by using the tubing recommended by the manufacturer of the sensors and the method of installation developed by the Colorado Highway Department. Another possible source of error, however, does exist in any system employing nuclear probes, decay of the probe's radioactive sources. As the radioactive source decays, it emits fewer particles into the surrounding mass, thereby, reducing the potential for back scatter and detection by the instrument. The rate of decay of this radioactive source is measured by the half-life of the source and is an exponential function of time. The error caused by this decay is therefore very small if the probes are recalibrated periodically and the radioactive sources have long half-lives. The effect of this possible error source is considered to be insignificant for this investigation because of the short time interval between the calibration of the tools and their use, also the long half-lives of the radioactive sources, 458 years for the Americium-Beryllium source of the moisture gauge and 30 years for the Cesium-137 source of the depth density gauge.

The data collected by this investigation with the moisture and density probes is, however, subject to significant random error caused by the variations in the conditions at the test site which affect the emission, scatter and detection of the radioactive particles. This error source was reduced by using ratio of the background count and measured particle count. Even with this method, the variations are of significant magnitude that the data should not be interpreted on a day to day basis but rather on a long-range trend basis as was done in this investigation.

CONDUCTIVITY

The conductivity data collected at the Cut Test Site contains no apparent systematic error. This apparent absence of error is due to the quality of the sensing system used, the Schlumberger 5FF40 Induction Well Logging Tool and the procedures used when drilling the hole for the sensor. This is not to indicate that the use of this logging tool is always without systematic error, as it is in the investigation at the Cut Site. Systematic errors are possible in this system due to the use of metal casing, mud as a circulatory media, or variation in bed thickness, however none of these possible sources were present in this test location and consultation with Mr. R. E. Hillar, Division Engineer, Schlumberger Well Services, indicated that the data was of sufficient quality that it could be used without correction or error consideration.

AXIAL STRAIN

As with all of the sensors used at this investigation, the overall effectiveness of the extensometer depends on the care with which the instrument was installed and the care used in taking the measurements. Due to the multielement design of this sensor and the related use of each element in reducing the data, there are very few possible systematic error sources. The only potential error sources stem from conditions related to the installation location and care of the sensing head. In wet installations, subject to freezing temperature, ice accumulation in the sensing head may cause considerable error as will any mistreatment of the head or collar anchor. Severe temperature variations between the anchor and sensing head can cause error, approximately 0.0267 percent per degree Fahrenheit; this is, therefore, of little consequence except at surface installations on alpine slopes where the head temperature may vary 50 degrees daily (5). Because the sensing head was protected from any water by the manhole arrangement (Fig. 16), the possibility of error caused by damage to the sensing was reduced. Errors due to sensing wire elongation are possible but are considered to be of little importance because of the relatively short lengths of wire used at this location.

HORIZONTAL DISPLACEMENT

The possible sources of systematic errors present in the Strain-Gauge type inclinometer used at the Cut Test Site are so numerous and large in magnitude that the data collected from this sensor is considered to be of no value. As in any sensor using strain gauges as the measuring component, this instrument is subject to error due to the creep in the strain gauge bond, zero drift due to intergranular adjustments in the cantilever steel, and temperature differences between the measuring bridge and the inclinometer. However, as it was noted in the discussion of the inclinometer, it would be possible to eliminate these sources of error by redesigning the instrument so that the measuring procedure developed by the Swedish Geotechnical Institute could be used.

Systematic errors caused by the use of strain gauges were not the only errors in the system used at the Cut Test Site. After use of the inclinometer was terminated it was discovered that during the course of the investigation the strain analyser used as read-out equipment was not functioning properly. This malfunction was not noticed until the analyser was used for another purpose. Investigation of the data indicated that it is impossible to determine when this unit began to malfunction, indicating that the damage may have been done to the instrument during transportation to the test area, making the entire body of data collected in error.

The preceeding discussion is not to imply that any inclinometer constructed, using strain gauges, would be of no value unless the Swedish Geotechnical Institute measuring procedure was used. Construction of a quality instrument with sufficient temperature compensation and adequate bonding of the strain gauges to the leaf spring would yield data of sufficient quality for consideration, without employing any form of compensating measuring procedure.

TEMPERATURE

Due to the simplicity of the system used to monitor the temperature of the soil mass there are very few possible sources of error associated with the temperature data. Error in the temperature readings could result from any changes in electrical resistance in the measuring system. An increase in the resistance caused by corrosion of any contact, wear in the signal wire due to accumulation of dust, dirt, or ice will cause the indicated temperature to be lower than the actual temperature. The effect of this increase in temperature is thought to be negligible at the Cut Test Site except as noted in the discussion of the results, because care was taken to adequately protect the connections and signal cables. Therefore, the temperature data can be considered to be free of systematic errors.

WATER LEVEL

The majority of the errors present in the water level data are of the random variety and considered to be of little significance. Systematic error may be caused by the addition of water to the ground water through the hole in which the level is being monitored. This addition caused by rain or melting snow will create an apparent increase in ground water level. To avoid this error source at the Cut Test Site, a rubber stopper was placed in the casing of the hole. The use of this preventative measure and the absence of any sudden increase in water level makes it possible to use the water level data without correction.

CONCLUSION

1. The methods and instruments used by the study to monitor temperature, moisture, density, conductivity, axial strain, and water level were satisfactory.
2. The inclinometer used by the study was unsatisfactory.
3. The pressure sensor used during the study was a source of much systematic error due to inclusion effect.
4. The cut investigated is stable.
5. The ground water present in the cut could cause trouble.

Suggestions for Continued Investigation of the Cut Test Site

1. The ground water level in the median should continue to be monitored.
2. Instrumentation should be installed to determine the direction of the ground water flow in the median.
3. Preventative measures should be initiated if the ground water level continues to rise.

Suggestions for Future Investigation

1. Investigations of this type should be continued using this study as a base.
2. Any future studies should have all sensors installed at the site one year prior to construction.
3. Investigation of new moisture and density probes should be included in the study.

4. The true soil stress should be monitored and the study should include an investigation of the sensors available for this purpose.
5. Construction of an inclinometer superior to the one used in this study should be included in any future study.
6. A more detailed preliminary investigation of the site should be undertaken to avoid the difficulties encountered by this study.
7. Samples of the shale from the test site should be tested in the laboratory to determine the properties of the shale.

LITHIFIED SHALE PROJECT

APPENDIX A

PRESSURE DATA

APPENDIX A

PRESSURE DATA

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
12	8	67	0	13.50
12	11	67	3	12.75
12	12	67	4	12.50
12	13	67	5	12.25
12	14	67	6	10.00
12	15	67	7	12.00
12	18	67	10	11.50
12	19	67	11	11.50
12	21	67	13	11.00
12	22	67	14	10.75
12	27	67	19	10.50
12	28	67	20	10.00
1	3	68	25	10.50
1	4	68	26	10.25
1	8	68	30	10.25
1	11	68	33	10.00
1	15	68	37	10.00
1	23	68	45	9.75
1	25	68	47	9.50
2	2	68	54	9.25
2	9	68	61	9.00
2	16	68	68	8.75
2	24	68	76	8.50
2	25	68	77	8.50
2	26	68	78	8.50
2	27	68	79	8.50
2	28	68	80	8.50
2	29	68	81	8.50
3	2	68	84	8.25
3	3	68	85	8.25
3	4	68	86	8.50
3	5	68	87	8.25
3	6	68	88	8.25
3	7	68	89	8.50
3	8	68	90	8.25
3	9	68	91	8.25
3	10	68	92	8.25
3	11	68	93	8.25
3	12	68	94	8.25
3	13	68	95	8.25

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
3	14	68	96	8.25
3	15	68	97	8.00
3	16	68	98	6.50
3	21	68	103	5.50
3	22	68	104	5.50
3	23	68	105	5.50
3	24	68	106	5.50
3	25	68	107	5.25
3	26	68	108	5.50
3	27	68	109	5.50
3	28	68	110	5.75
3	29	68	111	5.75
3	30	68	112	6.00
3	31	68	113	6.25
4	1	68	113	6.50
4	2	68	114	6.50
4	3	68	115	6.75
4	4	68	116	7.00
4	5	68	117	7.00
4	6	68	118	6.75
4	7	68	119	6.75
4	8	68	120	6.75
4	9	68	121	7.00
4	10	68	122	7.00
4	11	68	123	7.00
4	12	68	124	6.50
4	13	68	125	6.50
4	14	68	126	6.50
4	15	68	127	6.50
4	16	68	128	6.50
4	17	68	129	6.75
4	18	68	130	6.75
4	19	68	131	6.50
4	20	68	132	6.50
4	21	68	133	6.50
4	22	68	134	6.50
4	23	68	135	6.50
4	24	68	136	6.50
4	25	68	137	6.50
4	26	68	138	6.50
4	27	68	139	6.50
4	28	68	140	6.50
4	29	68	141	6.50
4	30	68	142	6.25
5	1	68	143	6.25
5	4	68	146	6.25
5	6	68	148	6.25
5	8	68	150	6.25
5	10	68	152	6.25
5	13	68	155	6.25

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
5	15	68	157	6.25
5	17	68	159	6.25
5	20	68	162	6.25
5	22	68	164	6.25
5	24	68	166	6.25
5	27	68	169	6.25
5	29	68	171	6.25
5	31	68	173	6.25
6	3	68	175	6.00
6	5	68	177	6.00
6	8	68	180	6.00
6	10	68	182	6.25
6	12	68	184	6.00
6	15	68	187	6.00
6	17	68	189	6.25
6	19	68	191	6.25
6	25	68	197	6.00
6	28	68	200	6.00
7	1	68	203	6.00
7	4	68	206	6.00
7	6	68	208	6.00
7	8	68	210	6.00
7	11	68	213	6.00
7	13	68	215	6.00
7	16	68	218	6.00
7	18	68	220	6.00
7	20	68	222	6.00
7	22	68	224	6.00
7	25	68	227	6.00
7	27	68	229	6.00
7	30	68	232	6.00
8	1	68	233	6.00
8	3	68	235	6.00
8	6	68	238	6.00
8	8	68	240	6.00
8	10	68	242	6.00
8	13	68	245	6.00
8	15	68	247	6.00
8	17	68	249	6.00
8	24	68	256	5.75
8	27	68	259	5.75
8	29	68	261	5.75
8	31	68	263	5.75
9	3	68	265	5.75
9	5	68	267	5.75
9	7	68	269	5.75
9	10	68	272	5.75
9	12	68	274	5.75
9	14	68	276	5.75
9	17	68	279	5.75

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
9	19	68	281	5.75
9	21	68	283	5.50
9	24	68	286	5.50
9	26	68	288	5.50
9	28	68	290	5.50
10	1	68	293	5.50
10	3	68	295	5.50
10	5	68	297	5.50
10	7	68	299	5.50
10	9	68	301	5.25
10	12	68	304	5.25
10	14	68	306	5.25
10	16	68	308	5.25
10	19	68	311	5.25
10	21	68	313	5.25
10	23	68	315	5.25
10	26	68	318	5.25
10	28	68	320	5.25
10	30	68	322	5.25
11	2	68	324	5.25
11	4	68	326	5.25
11	6	68	328	5.00
11	9	68	331	5.00
11	11	68	333	5.00
11	13	68	335	5.00
11	16	68	338	5.00
11	18	68	340	5.00
11	20	68	342	5.00
11	23	68	345	5.00
11	25	68	347	5.00
11	27	68	349	5.00
11	30	68	352	5.00
12	2	68	354	5.00
12	4	68	356	5.00
12	7	68	359	5.00
12	9	68	361	5.00
12	11	68	363	5.00
12	14	68	366	5.00
12	16	68	368	5.00
12	18	68	370	5.00
12	21	68	373	5.00
12	23	68	375	5.00
12	26	68	378	5.00
12	28	68	380	5.00
12	31	68	383	5.00
1	2	69	384	4.75
1	4	69	386	4.75
1	6	69	388	4.75
1	8	69	390	4.75
1	11	69	393	4.75

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
1	13	69	395	4.75
1	15	69	397	4.75
1	18	69	400	4.75
1	20	69	402	4.75
1	22	69	404	4.75
1	25	69	407	4.75
1	27	69	409	4.75
1	29	69	411	4.75
2	1	69	413	4.75
2	3	69	415	4.50
2	5	69	417	4.50
2	8	69	420	4.50
2	10	69	422	4.50
2	12	69	424	4.25
2	15	69	427	4.25
2	17	69	429	4.25
2	19	69	431	4.25
2	22	69	434	4.25
2	24	69	436	4.25
2	26	69	438	4.25
3	1	69	443	4.25
3	3	69	445	4.25
3	5	69	447	4.25
3	8	69	450	4.25
3	10	69	452	4.25
3	12	69	454	4.25
3	15	69	457	4.25
3	17	69	459	4.25
3	19	69	461	4.25
3	22	69	464	4.25
3	24	69	466	4.25
3	26	69	468	4.25
3	27	69	469	4.25
3	31	69	473	4.25
4	4	69	476	4.25
4	5	69	477	4.25
4	7	69	479	4.25
4	9	69	481	4.25
4	12	69	484	4.25
4	14	69	486	4.25
4	16	69	488	4.25
4	19	69	491	4.25
4	21	69	493	4.25
4	23	69	495	4.25
4	26	69	498	4.25
4	28	69	500	4.25
4	30	69	502	4.25
5	3	69	505	4.25
5	5	69	507	4.25
5	7	69	509	4.25

MONTH	DAY	YEAR	DAYS	PRESSURE PSI
5	10	69	512	4.25
5	12	69	514	4.25
5	14	69	516	4.25
5	17	69	519	4.25
5	19	69	521	4.25
5	21	69	523	4.25
5	24	69	526	4.25
5	26	69	528	4.25
5	28	69	530	4.25
5	31	69	533	4.25

LITHIFIED SHALE PROJECT

APPENDIX B

MOISTURE & DENSITY DATA

APPENDIX B

MOISTURE AND DENSITY DATA

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
8	24	68	256	3	131.6	
				5	127.2	
				7	141.1	
8	27	68	259	3	131.7	
				5	127.6	
				7	142.0	
8	29	68	261	3	134.3	
				5	129.5	
				7	140.8	
8	31	68	263	3	141.0	
				5	129.5	
				7	141.0	
9	3	68	265	3	133.7	
				5	129.5	
				7	140.9	
9	5	68	267	3	134.1	
				5	129.9	
				7	140.1	
9	7	68	269	3	134.1	
				5	129.8	
				7	140.3	
9	10	68	272	3	133.6	
				5	130.9	
				7	139.2	
9	12	68	274	3	133.0	
				5	130.2	
				7	138.0	
9	14	68	276	3	130.1	
				5	127.9	
				7	136.9	
9	17	68	279	3	131.9	
				5	129.5	
				7	137.5	
9	19	68	281	3	131.7	
				5	129.9	
				7	137.3	
9	21	68	283	3	135.5	
				5	131.9	
				7	140.8	
9	24	68	286	3	139.6	
				5	134.7	
				7	145.0	

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
9	26	68	288	3	139.6	
				5	135.3	
				7	144.9	
9	28	68	290	3	139.4	
				5	135.3	
				7	144.7	
10	1	68	293	3	139.4	
				5	135.5	
				7	144.4	
10	3	68	295	3	139.5	
				5	135.5	
				7	144.3	
10	5	68	297	3	125.9	
				5	121.7	
				7	132.6	
10	7	68	299	3	128.7	
				5	124.6	
				7	135.8	
10	9	68	301	3	130.0	
				5	126.7	
				7	137.7	
10	12	68	304	3	132.7	
				5	127.8	
				7	138.2	
10	14	68	306	3	129.7	
				5	124.9	
				7	137.5	
10	16	68	308	3	128.8	
				5	126.9	
				7	135.4	
10	19	68	311	3	130.7	
				5	127.5	
				7	137.4	
10	21	68	313	3	129.1	
				5	128.1	
				7	133.6	
10	23	68	315	3	126.6	
				5	125.2	
				7	130.3	
10	26	68	318	3	128.2	
				5	122.3	
				7	134.5	
10	28	68	320	3	124.1	
				5	120.0	
				7	133.2	
10	30	68	322	3	124.8	
				5	117.9	
				7	132.4	
11	2	68	324	3	128.6	10.9
				5	119.1	12.2

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
				7	130.0	12.8
11	4	68	326	3	127.3	10.7
				5	118.2	12.1
				7	132.5	12.5
11	6	68	328	3	126.2	9.9
				5	120.1	11.6
				7	132.7	11.9
11	9	68	331	3	128.5	10.2
				5	124.8	11.9
				7	134.6	12.1
11	11	68	333	3	126.1	10.6
				5	121.8	12.2
				7	131.4	12.8
11	13	68	335	3	126.8	10.1
				5	124.3	11.9
				7	131.6	12.2
11	16	68	338	3	129.0	10.1
				5	125.6	11.8
				7	130.7	12.3
11	18	68	340	3	135.0	13.9
				5	131.5	18.8
				7	138.2	21.5
11	20	68	342	3	132.3	14.4
				5	127.5	17.8
				7	140.5	13.2
11	23	68	345	3	130.4	10.3
				5	126.7	11.9
				7	139.9	12.4
11	25	68	347	3	131.7	10.3
				5	128.4	11.7
				7	141.1	12.3
11	27	68	349	3	134.1	10.4
				5	131.2	11.6
				7	143.6	12.4
11	30	68	352	3	149.2	
				5	128.1	15.7
				7	141.5	
12	2	68	354	3	132.3	19.8
				5	128.4	13.1
				7	141.3	
12	4	68	356	3	132.3	10.6
				5	128.8	11.0
				7	141.0	10.6
12	7	68	359	3	132.0	10.2
				5	128.9	10.6
				7	138.2	10.4
12	9	68	361	3	137.1	10.7
				5	133.9	11.4
				7	142.8	10.7
12	11	68	363	3	134.0	11.1

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
				5	129.0	11.9
				7	138.4	11.4
12	14	68	366	3	133.6	11.3
				5	130.5	13.7
				7	139.9	12.6
12	16	68	368	3	131.5	10.1
				5	128.3	10.5
				7	137.6	10.9
12	21	68	373	3	131.4	8.5
				5	127.9	10.0
				7	136.8	10.0
12	23	68	375	3	131.4	9.1
				5	127.7	9.3
				7	137.1	9.9
12	26	68	378	3	131.6	8.9
				5	128.5	9.6
				7	137.8	9.9
12	28	68	380	3	131.7	
				5	128.9	
				7	137.8	
12	31	68	383	3	132.5	.1
				5	129.7	2.1
				7	137.5	5.4
1	2	69	384	3	132.1	13.7
				5	129.2	14.4
				7	137.3	14.2
1	4	69	386	3	131.8	14.2
				5	128.4	14.7
				7	137.1	14.5
1	6	69	388	3	131.7	13.4
				5	127.5	14.1
				7	137.5	13.8
1	8	69	390	3	131.5	11.8
				5	127.4	12.6
				7	137.0	12.0
1	11	69	393	3	131.5	10.5
				5	127.5	13.6
				7	137.2	13.8
1	13	69	395	3	131.7	10.5
				5	127.8	13.4
				7	137.4	13.2
1	15	69	397	3	131.5	10.6
				5	127.5	13.2
				7	137.3	13.1
1	18	69	400	3	131.8	10.3
				5	128.5	13.0
				7	137.6	13.2
1	20	69	402	3	132.3	10.1
				5	128.8	12.9
				7	138.5	13.2

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
1	22	69	404	3	131.9	9.1
				5	128.4	11.5
				7	137.6	11.6
1	25	69	407	3	131.3	7.9
				5	127.9	12.3
				7	137.3	12.5
1	27	69	409	3	130.6	7.8
				5	127.1	9.6
				7	137.2	8.7
1	29	69	411	3	128.6	7.0
				5	124.0	9.1
				7	133.0	7.9
2	1	69	413	3	128.9	7.3
				5	125.8	8.6
				7	132.0	8.2
2	3	69	415	3	128.6	7.4
				5	125.7	9.1
				7	132.0	8.7
2	5	69	417	3	131.4	8.4
				5	128.0	9.2
				7	135.8	8.5
2	8	69	420	3	129.8	9.6
				5	126.7	9.7
				7	137.2	9.5
2	10	69	422	3	128.3	9.2
				5	123.7	9.5
				7	132.7	9.1
2	12	69	424	3	125.8	9.6
				5	122.5	9.7
				7	131.6	9.5
2	15	69	427	3	126.5	10.7
				5	120.4	10.8
				7	128.9	9.8
2	17	69	429	3	125.0	10.5
				5	119.9	10.6
				7	127.2	10.5
2	19	69	431	3	125.5	12.8
				5	122.2	13.5
				7	130.5	13.4
2	22	69	434	3	126.2	12.4
				5	121.8	13.3
				7	130.4	13.2
2	24	69	436	3	125.8	12.6
				5	122.1	13.3
				7	130.3	13.2
2	26	69	438	3	125.6	12.6
				5	122.2	13.3
				7	130.5	13.2
3	5	69	447	3	125.5	12.6
				5	122.2	13.2

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
				7	130.3	13.2
3	8	69	450	3	125.5	12.1
				5	122.5	12.8
				7	130.5	12.7
3	10	69	452	3	127.8	11.9
				5	124.0	12.6
				7	131.6	12.6
3	12	69	454	3	130.5	11.5
				5	126.0	12.2
				7	136.0	11.9
3	15	69	457	3	116.2	11.5
				5	110.4	12.2
				7	135.1	12.1
3	17	69	459	3	129.8	11.8
				5	127.1	12.2
				7	135.2	12.1
3	19	69	461	3	127.8	11.7
				5	126.0	11.9
				7	136.7	12.1
3	22	69	464	3	125.5	11.4
				5	122.8	11.6
				7	135.9	11.8
3	24	69	466	3	128.5	11.1
				5	124.9	11.1
				7	138.7	11.8
4	4	69	476	3	129.7	10.9
				5	126.4	11.6
				7	139.8	11.7
4	5	69	477	3	129.0	10.9
				5	126.1	11.6
				7	140.1	11.7
4	7	69	479	3	129.0	10.9
				5	126.1	11.6
				7	140.0	11.7
4	9	69	481	3	129.1	10.8
				5	126.2	11.5
				7	140.0	11.7
4	12	69	484	3	129.1	10.9
				5	125.9	11.5
				7	139.4	11.7
4	14	69	486	3	127.3	10.9
				5	125.3	11.5
				7	139.3	11.8
4	16	69	488	3	128.5	11.0
				5	125.5	11.6

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
				7	139.6	11.8
4	19	69	491	3	130.8	11.0
				5	127.5	11.6
				7	137.1	11.8
4	21	69	493	3	130.3	11.0
				5	127.5	11.6
				7	137.3	11.8
4	23	69	495	3	129.8	11.0
				5	126.5	11.6
				7	135.9	11.8
4	26	69	498	3	129.7	11.0
				5	126.5	11.6
				7	136.0	11.9
4	28	69	500	3	130.0	11.0
				5	126.7	11.7
				7	136.1	11.9
4	30	69	502	3	129.8	11.0
				5	126.5	11.6
				7	135.9	11.9
5	3	69	505	3	129.7	11.0
				5	126.6	11.6
				7	136.0	11.8
5	5	69	507	3	129.5	11.0
				5	126.5	11.6
				7	136.0	11.9
5	7	69	509	3	129.6	11.0
				5	126.7	11.6
				7	136.1	11.9
5	10	69	512	3	130.0	11.0
				5	127.7	11.6
				7	137.2	11.9
5	12	69	514	3	128.9	11.0
				5	126.6	11.6
				7	136.2	11.9
5	14	69	516	3	129.1	11.0
				5	126.3	11.6
				7	136.0	11.8
5	17	69	519	3	129.0	11.0
				5	126.1	11.6
				7	135.8	11.9
5	19	69	521	3	130.2	11.0
				5	128.7	11.6
				7	137.0	11.8
5	21	69	523	3	129.6	11.0
				5	127.7	11.6
				7	137.3	11.8
5	24	69	526	3	129.9	11.0
				5	127.5	11.6

MONTH	DAY	YEAR	DAYS	FEET	DENSITY LBS/CU FT	MOISTURE LBS/CU FT
				7	137.0	11.8
5	26	69	528	3	130.2	11.0
				5	128.0	11.6
				7	137.5	11.9
5	28	69	530	3	130.2	11.0
				5	128.1	11.6
				7	137.6	11.9
5	31	69	533	3	130.5	11.0
				5	128.5	11.6
				7	138.1	11.9

LITHIFIED SHALE PROJECT

APPENDIX C

CONDUCTIVITY DATA

APPENDIX C

CONDUCTIVITY DATA

MONTH	DAY	YEAR	DAYS	CENTIMHOS
3	16	68	98	7.00
3	21	68	103	7.60
3	22	68	104	7.60
3	23	68	105	7.50
3	24	68	106	7.60
3	25	68	107	7.60
3	26	68	108	7.60
3	27	68	109	7.60
3	28	68	110	8.00
3	29	68	111	7.60
3	30	68	112	7.80
3	31	68	113	7.60
4	1	68	113	7.80
4	2	68	114	7.80
4	3	68	115	7.80
4	4	68	116	7.60
4	5	68	117	7.60
4	6	68	118	7.60
4	7	68	119	7.60
4	8	68	120	7.60
4	9	68	121	7.60
4	10	68	122	7.60
4	11	68	123	7.60
4	12	68	124	7.60
4	13	68	125	7.60
4	14	68	126	7.60
4	15	68	127	7.40
4	16	68	128	7.50
4	17	68	129	7.60
4	18	68	130	7.60
4	19	68	131	7.50
4	20	68	132	7.50
4	21	68	133	7.50
4	22	68	134	7.50
4	23	68	135	7.50
4	24	68	136	7.50
4	25	68	137	7.50
4	26	68	138	7.50
4	27	68	139	7.50
4	28	68	140	7.50
4	29	68	141	7.50
4	30	68	142	7.50
5	1	68	143	7.50
5	4	68	146	7.50
5	6	68	148	7.50

MONTH	DAY	YEAR	DAYS	CENTIMHOS
5	8	68	150	7.50
5	10	68	152	7.50
5	13	68	155	7.50
5	15	68	157	7.50
5	17	68	159	7.50
5	20	68	162	7.50
5	22	68	164	7.50
5	24	68	166	7.50
5	27	68	169	7.50
5	29	68	171	7.50
5	31	68	173	7.50
6	3	68	175	7.50
6	5	68	177	7.50
6	8	68	180	7.50
6	10	68	182	7.50
6	12	68	184	
6	15	68	187	
6	17	68	189	
6	19	68	191	
6	25	68	197	7.60
6	28	68	200	7.50
7	1	68	203	7.50
7	4	68	206	7.80
7	6	68	208	7.80
7	8	68	210	7.70
7	11	68	213	7.70
7	13	68	215	7.70
7	16	68	218	7.70
7	18	68	220	7.70
7	20	68	222	7.70
7	22	68	224	7.70
7	25	68	227	7.70
7	27	68	229	7.70
7	30	68	232	7.70
8	1	68	233	7.70
8	3	68	235	7.60
8	6	68	238	7.60
8	8	68	240	7.60
8	10	68	242	7.60
8	13	68	245	7.60
8	15	68	247	7.60
8	17	68	249	
8	24	68	256	8.00
8	27	68	259	8.00
8	29	68	261	8.00
8	31	68	263	8.00
9	3	68	265	8.00
9	5	68	267	8.00
9	7	68	269	8.00
9	10	68	272	8.00

MONTH	DAY	YEAR	DAYS	CENTIMHOS
9	12	68	274	8.00
9	14	68	276	8.00
9	17	68	279	8.00
9	19	68	281	8.00
9	21	68	283	8.00
9	24	68	286	8.00
9	26	68	288	8.00
9	28	68	290	8.00
10	1	68	293	8.00
10	3	68	295	8.00
10	5	68	297	8.00
10	7	68	299	8.00
10	9	68	301	8.00
10	12	68	304	8.00
10	14	68	306	8.00
10	16	68	308	8.00
10	19	68	311	8.00
10	21	68	313	8.00
10	23	68	315	8.00
10	26	68	318	8.00
10	28	68	320	8.00
10	30	68	322	8.00
11	2	68	324	8.00
11	4	68	326	8.00
11	6	68	328	8.00
11	9	68	331	8.00
11	11	68	333	8.00
11	13	68	335	8.00
11	16	68	338	8.00
11	18	68	340	8.00
11	20	68	342	8.00
11	23	68	345	8.00
11	25	68	347	8.00
11	27	68	349	8.00
11	30	68	352	8.00
12	2	68	354	8.00
12	4	68	356	8.00
12	7	68	359	8.00
12	9	68	361	8.00
12	11	68	363	8.00
12	14	68	366	8.00
12	16	68	368	8.00
12	18	68	370	8.00
12	21	68	373	8.00
12	23	68	375	8.00
12	26	68	378	8.00
12	28	68	380	8.00
12	31	68	382	8.00
1	2	69	384	8.00
1	4	69	386	8.00

MONTH	DAY	YEAR	DAYS	CENTIMHOS
1	6	69	388	8.00
1	8	69	390	8.00
1	11	69	393	8.00
1	13	69	395	8.00
1	15	69	397	8.00
1	18	69	400	8.00
1	20	69	402	8.00
1	22	69	404	
1	25	69	407	
1	27	69	409	
1	29	69	411	
2	1	69	413	
2	3	69	415	
2	5	69	417	
2	8	69	420	
2	10	69	422	
2	12	69	424	
2	15	69	427	
2	19	69	431	
2	17	69	429	
2	22	69	434	7.60
2	24	69	436	7.60
2	26	69	438	7.60
3	1	69	443	7.60
3	3	69	445	7.60
3	5	69	447	7.60
3	8	69	450	7.60
3	10	69	452	7.60
3	12	69	454	7.60
3	15	69	457	7.60
3	17	69	459	7.60
3	19	69	461	7.60
3	22	69	464	7.60
3	24	69	466	7.60
3	26	69	468	7.60
3	27	69	469	7.60
3	31	69	473	7.60
4	4	69	476	7.60
4	5	69	477	7.60
4	7	69	479	7.60
4	9	69	481	7.60
4	12	69	484	7.60
4	14	69	486	7.60
4	16	69	488	7.60
4	19	69	491	7.60
4	21	69	493	7.60
4	23	69	495	7.60
4	26	69	498	7.60
4	28	69	500	7.60
4	30	69	502	7.60

MONTH	DAY	YEAR	DAYS	CENTIMHOS
5	3	69	505	7.60
5	5	69	507	7.60
5	7	69	509	7.60
5	10	69	512	7.60
5	12	69	514	7.60
5	14	69	516	7.60
5	17	69	519	7.60
5	19	69	521	7.60
5	21	69	523	7.60
5	24	69	526	7.60
5	26	69	528	7.60
5	28	69	530	7.60
5	31	69	533	7.60

LITHIFIED SHALE PROJECT

APPENDIX D

EXTENTIOMETER DATA

APPENDIX D

CORRECTED AXIAL STRAIN DATA

EXTENTIOMETER READINGS IN INCHES

MONTH	DAY	YEAR	DAYS	7 FT	13 FT	19 FT	25 FT
8	20	68	251	.767	.726	.865	.831
8	24	68	255	.781	.710	.919	.873
8	27	68	258	.783	.728	.919	.873
8	29	68	260	.782	.729	.920	.873
8	31	68	262	.783	.792	.920	.873
9	3	68	264	.783	.730	.921	.874
9	5	68	266	.783	.731	.921	.875
9	7	68	268	.783	.730	.921	.875
9	10	68	271	.783	.730	.921	.875
9	12	68	273	.783	.730	.921	.875
9	14	68	275	.783	.731	.921	.875
9	17	68	278	.783	.731	.921	.875
9	19	68	280	.782	.731	.920	.874
9	21	68	282	.782	.730	.920	.874
9	24	68	285	.752	.730	.920	.874
9	26	68	287	.752	.731	.921	.875
9	28	68	289	.783	.732	.923	.877
10	1	68	292	.754	.732	.923	.878
10	3	68	294	.755	.733	.924	.875
10	4	68	295	.782	.731	.922	.874
10	5	68	296	.783	.731	.922	.875
10	9	68	300	.782	.730	.921	.874
10	12	68	303	.780	.729	.920	.873
10	14	68	305	.751	.730	.920	.875
10	16	68	307	.781	.730	.921	.875
10	19	68	310	.752	.731	.922	.875
10	21	68	312	.781	.731	.922	.875
10	23	68	314	.782	.732	.922	.875
10	26	68	317	.782	.732	.932	.875
10	28	68	319	.782	.732	.923	.875
10	30	68	321	.783	.732	.923	.875
11	2	68	323	.783	.733	.924	.875
11	4	68	325	.783	.733	.923	.875
11	6	68	327	.783	.732	.923	.875
11	9	68	330	.783	.732	.923	.875
11	11	68	332	.782	.732	.922	.875
11	13	68	334	.782	.732	.922	.875
11	16	68	337	.782	.732	.922	.875
11	18	68	339	.781	.732	.922	.875
11	20	68	341	.780	.730	.920	.874
11	23	68	344	.778	.727	.919	.872
11	25	68	346	.779	.725	.919	.873
11	27	68	348	.781	.723	.920	.875
11	30	68	351	.780	.725	.921	.875
12	2	68	353	.784	.727	.924	.879

MONTH	DAY	YEAR	DAYS	7 FT	13 FT	19 FT	25 FT
12	4	68	355	.786	.731	.927	.881
12	7	68	358	.787	.733	.929	.882
12	9	68	360	.789	.737	.930	.883
12	11	68	362	.790	.739	.933	.885
12	14	68	365	.795	.745	.936	.890
12	16	68	367	.796	.745	.937	.890
12	18	68	369	.796	.745	.937	.890
12	21	68	372	.796	.745	.937	.890
12	23	68	374	.796	.745	.937	.890
12	26	68	377	.796	.745	.937	.890
12	28	68	379	.796	.745	.937	.890
12	31	68	382	.797	.747	.940	.892
1	2	69	383	.797	.747	.939	.891
1	4	69	385	.797	.746	.937	.890
1	6	69	387	.797	.746	.937	.890
1	8	69	389	.797	.746	.937	.890
1	11	69	392	.797	.745	.937	.889
1	13	69	394	.797	.745	.937	.889
1	15	69	396	.797	.745	.937	.889
1	18	69	399	.797	.740	.938	.890
1	20	69	401	.797	.746	.938	.890
1	22	69	403	.798	.746	.938	.892
1	25	69	406	.798	.746	.938	.893
1	27	69	408	.798	.747	.939	.893
1	29	69	410	.799	.747	.939	.893
2	1	69	412	.799	.747	.939	.893
2	3	69	414	.799	.747	.939	.893
2	5	69	416	.799	.747	.939	.893
2	8	69	419	.798	.747	.939	.893
2	12	69	424	.798	.747	.939	.892
2	17	69	429	.798	.747	.939	.892
2	22	69	434	.798	.747	.938	.892
2	24	69	436	.799	.747	.938	.892
2	26	69	438	.799	.747	.938	.891
3	1	69	443	.799	.747	.938	.891
3	3	69	445	.799	.747	.938	.891
3	5	69	447	.799	.747	.938	.891
3	8	69	450	.799	.747	.938	.891
3	10	69	452	.799	.747	.938	.892
3	12	69	454	.799	.948	.939	.893
3	15	69	457	.799	.748	.940	.895
3	17	69	459	.801	.748	.942	.895
3	19	69	461	.803	.749	.943	.896
3	22	69	464	.803	.749	.943	.896
3	24	69	466	.804	.750	.944	.896
3	26	69	468	.804	.751	.944	.897
3	29	69	471	.806	.754	.946	.899
3	31	69	473	.806	.754	.946	.899
4	4	69	476	.806	.754	.946	.899
4	5	69	477	.806	.754	.946	.899

MONTH	DAY	YEAR	DAYS	7 FT	13 FT	19 FT	25 FT
4	7	69	479	.806	.754	.946	.899
4	9	69	481	.806	.754	.945	.899
4	12	69	484	.806	.754	.945	.898
4	14	69	486	.806	.753	.944	.897
4	16	69	488	.805	.753	.943	.897
4	19	69	491	.804	.752	.943	.896
4	21	69	493	.805	.752	.943	.896
4	23	69	495	.805	.752	.943	.897
4	26	69	498	.805	.753	.943	.897
4	28	69	500	.805	.753	.943	.897
4	30	69	502	.805	.753	.743	.897
5	3	69	505	.805	.753	.944	.897
5	5	69	507	.806	.753	.944	.897
5	7	69	509	.806	.754	.944	.897
5	10	69	512	.806	.754	.944	.897
5	12	69	514	.806	.754	.944	.897
5	14	69	516	.806	.754	.944	.897
5	17	69	519	.805	.753	.943	.897
5	19	69	521	.805	.753	.943	.897
5	21	69	523	.805	.752	.944	.897
5	24	69	526	.805	.752	.944	.897
5	26	69	528	.805	.752	.944	.897
5	28	69	530	.805	.752	.944	.896
5	31	69	533	.805	.752	.945	.896

MONTH	DAY	YEAR	DAYS	31 FT	37 FT	43 FT	49 FT
8	20	68	251	.812	.768	.769	.757
8	24	68	255	.822	.769	.805	.794
8	27	68	258	.819	.768	.805	.795
8	29	68	260	.823	.769	.806	.796
8	31	68	262	.823	.769	.806	.796
9	5	68	266	.824	.770	.807	.797
9	7	68	268	.825	.770	.808	.797
9	10	68	271	.825	.770	.808	.797
9	12	68	273	.825	.770	.808	.797
9	14	68	275	.824	.771	.808	.797
9	17	68	278	.824	.771	.808	.797
9	19	68	280	.825	.771	.807	.796
9	21	68	282	.824	.770	.807	.796
9	24	68	285	.824	.770	.807	.796
9	26	68	287	.826	.771	.809	.796
9	28	68	289	.826	.771	.809	.798
10	1	68	292	.826	.772	.810	.795
10	3	68	294	.827	.772	.810	.799
10	4	68	295	.824	.768	.807	.797
10	5	68	296	.825	.768	.808	.797
10	9	68	300	.823	.766	.835	.796
10	12	68	303	.822	.765	.805	.795
10	14	68	305	.823	.766	.805	.797
10	16	68	307	.823	.766	.805	.797
10	19	68	310	.825	.767	.805	.797
10	21	68	312	.825	.767	.805	.797
10	23	68	314	.825	.768	.805	.796
10	26	68	317	.825	.769	.805	.796
10	28	68	319	.826	.769	.806	.796
10	30	68	321	.826	.769	.806	.796
11	2	68	323	.827	.773	.806	.795
11	4	68	325	.827	.773	.806	.795
11	6	68	327	.827	.773	.806	.795
11	9	68	330	.826	.773	.806	.796
11	11	68	332	.826	.773	.806	.796
11	13	68	334	.826	.772	.806	.797
11	16	68	337	.826	.772	.906	.797
11	18	68	339	.825	.772	.806	.797
11	20	68	341	.825	.770	.806	.795
11	23	68	344	.823	.769	.806	.794
11	25	68	346	.823	.769	.807	.795
11	27	68	348	.824	.770	.808	.796
11	30	68	351	.824	.770	.808	.797
12	2	68	353	.828	.773	.810	.799
12	4	68	355	.831	.775	.813	.802
12	7	68	358	.833	.778	.815	.804
12	9	68	360	.833	.780	.816	.805
12	11	68	362	.834	.781	.818	.806

MONTH	DAY	YEAR	DAYS	31 FT	37 FT	43 FT	49 FT
12	14	68	365	.838	.784	.821	.810
12	16	68	367	.840	.785	.823	.811
12	18	68	369	.840	.785	.822	.811
12	21	68	372	.840	.786	.822	.810
12	23	68	374	.840	.786	.822	.810
12	26	68	377	.840	.785	.822	.810
12	28	68	379	.839	.785	.822	.810
12	31	68	382	.841	.786	.825	.813
1	2	69	383	.841	.786	.825	.812
1	4	69	385	.840	.785	.824	.811
1	6	69	387	.840	.785	.824	.811
1	8	69	389	.840	.785	.823	.811
1	11	69	392	.839	.785	.822	.810
1	13	69	394	.839	.785	.822	.810
1	15	69	396	.839	.785	.822	.810
1	18	69	399	.840	.785	.824	.811
1	20	69	401	.840	.786	.824	.811
1	22	69	403	.840	.786	.824	.812
1	25	69	406	.841	.787	.825	.813
1	27	69	408	.841	.787	.825	.813
1	29	69	410	.841	.787	.825	.814
2	1	69	412	.841	.787	.825	.814
2	3	69	414	.841	.787	.825	.814
2	5	69	416	.841	.787	.825	.814
2	8	69	419	.841	.787	.825	.814
2	12	69	424	.841	.787	.824	.813
2	15	69	427	.841	.787	.824	.813
2	17	69	429	.841	.787	.824	.813
2	19	69	431	.841	.787	.824	.813
2	22	69	434	.841	.787	.824	.813
2	24	69	436	.841	.786	.823	.812
2	26	69	438	.841	.786	.823	.812
3	1	69	443	.841	.786	.823	.812
3	3	69	445	.841	.786	.823	.812
3	5	69	447	.841	.786	.823	.812
3	8	69	450	.841	.787	.823	.812
3	10	69	452	.841	.787	.824	.813
3	12	69	454	.842	.788	.824	.814
3	15	69	457	.843	.789	.825	.814
3	17	69	459	.843	.790	.827	.816
3	19	69	461	.845	.791	.830	.817
3	22	69	464	.845	.791	.830	.817
3	24	69	466	.845	.793	.830	.818
3	26	69	468	.847	.793	.830	.818
3	29	69	469	.849	.794	.831	.820
3	31	69	473	.849	.794	.831	.820
4	4	69	476	.849	.794	.831	.820
4	5	69	477	.849	.794	.831	.820
4	7	69	479	.849	.794	.831	.820
4	9	69	481	.849	.794	.831	.820

MONTH	DAY	YEAR	DAYS	31 FT	37 FT	43 FT	49 FT
4	12	69	484	.848	.793	.831	.820
4	14	69	486	.848	.792	.831	.818
4	16	69	488	.848	.792	.831	.818
4	19	69	491	.847	792	.831	.818
4	21	69	493	.847	.792	.831	.818
4	23	69	495	.847	.793	.832	.819
4	26	69	498	.848	793	.837	.819
4	28	69	500	.848	.793	.832	.819
4	30	69	502	.848	.794	.832	.819
5	3	69	505	.848	.794	.832	.819
5	5	69	507	.848	.794	.832	.819
5	7	69	509	.848	.794	.832	.819
5	10	69	512	.848	.794	.832	.819
5	12	69	514	.848	.794	.832	.819
5	14	69	516	.848	.794	.832	.819
5	17	69	519	.848	.794	.832	.819
5	19	69	521	.847	.794	.831	.818
5	21	69	523	.847	.793	.831	.818
5	24	69	526	.847	.793	.832	.818
5	26	69	528	.847	.793	.832	.818
5	28	69	530	.847	.793	.831	.818
5	31	69	533	.847	.792	.831	.818

LITHIFIED SHALE PROJECT

APPENDIX E

TEMPERATURE DATA

APPENDIX E

TEMPERATURE DATA

TEMPERATURE IN DEGREES CENTIGRADE

MONTH	DAY	YEAR	DAYS	SURFACE	COLLAR	48 FT	96 FT
3	16	68	98			9.71	9.99
3	17	68	99			9.71	9.99
3	18	68	100			9.71	9.99
3	19	68	101			9.44	9.58
3	20	68	102			9.58	9.85
3	21	68	103			9.58	9.85
3	22	68	104			9.58	9.85
3	23	68	105			9.44	9.71
3	24	68	106			9.58	9.71
3	25	68	107			9.58	9.71
3	26	68	108			10.56	9.58
3	27	68	139			9.44	9.71
3	28	68	220			9.58	9.85
3	29	68	222			9.58	9.71
3	30	68	112			9.58	9.71
3	31	68	113			9.58	9.71
4	1	68	114			9.44	9.71
4	2	68	115			9.44	9.71
4	3	68	116			9.44	9.71
4	4	68	117			9.44	9.71
4	5	68	118			9.44	9.71
4	6	68	119			9.44	9.72
4	7	68	120			9.44	9.71
4	9	68	122	19.87	3.52	9.58	9.71
4	10	68	123	20.09	3.41	9.44	9.71
4	12	68	125	10.85	4.25	9.44	9.71
4	13	68	126	1.27	3.82	9.44	9.71
4	14	68	127	14.47	3.52	9.44	9.71
4	15	68	128	13.80	3.62	9.44	9.71
4	16	68	129	7.60	3.82	9.44	9.71
4	17	68	130	14.47	3.52	9.44	9.71
4	18	68	131	14.81	3.30	9.44	9.71
4	19	68	132	15.16	3.10	9.44	9.72
4	20	68	133	11.43	3.52	9.44	9.71
4	21	68	134	8.63	3.52	9.30	9.71
4	22	68	135	0.45	3.10	9.44	9.71
4	23	68	136	14.14	4.25	9.44	9.71
4	24	68	137	13.97	3.52	9.44	9.71
4	25	68	138	15.31	3.93	9.44	9.71
4	26	68	139	15.31	4.47	9.44	9.71
4	27	68	140	10.13	3.62	9.44	9.71
4	28	68	141	11.58	4.58	9.44	9.71
4	29	68	142	12.34	5.12	9.44	9.72
4	30	68	143	20.32	5.47	9.44	9.71
5	1	68	144	22.93	6.03	9.44	9.71

MONTH	DAY	YEAR	DAYS	SURFACE	COLLAR	48 FT	96 FT
5	4	68	147	15.89	8.37	9.44	9.71
5	6	68	149	12.03	7.97	9.44	9.71
5	8	68	151	12.97	8.11	9.44	9.71
5	10	68	153	15.89	6.87	9.44	9.71
5	13	68	156	11.43	4.36	9.44	9.71
5	15	68	158	10.98	4.14	9.44	9.71
5	17	68	160	18.20	7.35	9.44	9.71
5	20	68	163	26.68	7.23	9.16	9.58
5	22	68	165	11.43	7.36	9.30	9.58
5	24	68	167	11.58	7.23	9.30	9.58
5	27	68	170	13.47	7.36	9.44	9.58
5	29	68	172	11.58	7.60	9.44	9.58
5	31	68	174	10.84	8.11	9.44	9.58
6	3	68	177	13.97	8.89	9.30	9.58
6	5	68	179	14.47	9.44	9.16	9.58
6	8	68	182	17.61	10.41	9.03	9.58
6	10	68	184	19.66	10.84	9.03	9.71
6	12	68	186	21.93	10.84	9.03	9.71
6	15	68	189	21.70	10.84	9.03	9.71
6	17	68	191	23.67	10.84	9.03	9.71
6	19	68	193	25.27	10.84	9.03	9.71
6	25	68	199	14.98	12.50	9.03	9.58
6	28	68	202	21.00	12.81	9.03	9.71
7	1	68	205	25.82	12.81	9.03	9.71
7	4	68	208	25.00	12.50	8.89	9.58
7	6	68	210	26.68	12.97	8.89	9.58
7	8	68	212	26.39	14.31	9.03	9.58
7	11	68	215	24.73	15.16	9.30	9.71
7	13	68	217	26.10	15.53	9.26	9.71
7	16	67	220	27.57	15.89	9.03	9.71
7	18	68	222	26.97	16.08	9.03	9.71
7	20	68	224	24.46	16.26	9.16	9.71
7	22	68	226	20.55	16.83	9.16	9.71
7	25	68	229	19.23	16.45	9.44	9.85
7	27	68	231	23.67	15.89	9.44	9.85
7	30	68	234	26.39	16.26	9.44	9.85
8	1	68	237	25.82	16.08	9.44	9.71
8	3	68	239	27.27	15.71	9.44	9.71
8	6	68	242	27.57	16.08	9.44	9.71
8	8	68	244	27.57	16.45	9.58	9.71
8	10	68	246	27.57	16.26	9.58	9.85
8	13	68	249	21.00	15.71	9.58	9.85
8	15	68	251	25.60	15.89	9.58	9.85
8	17	68	253	20.55	15.71	9.58	9.85
8	24	68	250	18.80	13.91	9.03	9.71
8	27	68	259	18.20	13.97	9.03	9.71
8	29	68	261	17.80	13.47	9.03	9.71
8	31	68	263	17.22	12.97	9.03	9.71
9	3	68	265	16.83	12.81	8.89	9.71
9	5	68	267	15.89	14.14	8.89	9.71

MONTH	DAY	YEAR	DAYS	SURFACE	COLLAR	48 FT	96 FT
9	7	68	269	14.98	12.97	8.89	9.71
9	10	68	272	14.64	12.81	8.89	9.71
9	12	68	274	14.81	12.81	9.03	9.58
9	14	68	276	21.23	12.66	9.03	9.58
9	17	68	279	24.19	13.97	9.03	9.58
9	19	68	281	23.41	12.50	9.30	9.58
9	21	68	283	23.92	12.97	9.30	9.58
9	24	68	286	26.39	11.13	9.44	9.58
9	26	68	288	26.10	10.84	9.30	9.58
9	28	68	290	23.41	10.70	9.44	9.58
10	1	68	293	15.53	10.70	9.30	9.58
10	3	68	295	13.97	10.98	9.16	9.58
10	5	68	297	10.56	9.58	9.58	9.85
10	7	68	299	21.47	9.16	9.44	9.71
10	9	68	301	22.17	8.89	9.44	9.71
10	12	68	304	21.70	8.50	9.44	9.71
10	14	68	306	21.93	8.63	9.44	9.71
10	16	68	308	21.70	8.76	9.44	9.71
10	19	68	311	21.70	8.63	9.44	9.71
10	21	68	313	21.93	8.63	9.44	9.71
10	23	68	315	19.87	8.50	9.44	9.71
10	26	68	318	19.66	8.50	9.44	9.71
10	28	68	320	13.30	6.99	9.44	9.71
10	30	68	322	12.34	6.75	9.44	9.71
11	2	68	324	12.81	6.87	9.44	9.71
11	4	68	326	9.16	6.99	9.44	9.71
11	6	68	328	7.36	5.24	9.44	9.71
11	9	68	331	7.23	5.35	9.44	9.71
11	11	68	333	6.99	5.12	9.44	9.71
11	13	68	335	5.92	4.90	9.44	9.71
11	16	68	338	4.14	4.79	9.44	9.71
11	18	68	340	2.61	4.58	9.44	9.71
11	20	68	342	2.51	4.25	9.44	9.71
11	23	68	345	6.51	3.93	9.58	9.71
11	25	68	347	5.58	3.93	9.55	9.71
11	27	68	349	4.68	3.82	9.58	9.71
11	30	68	352	3.93	3.72	9.58	9.71
12	2	68	354	3.82	3.62	9.58	9.71
12	4	68	356	1.93	3.31	9.44	9.58
12	7	68	359	-1.67	3.21	9.44	9.58
12	9	68	361	-1.75	3.10	9.44	9.58
12	11	68	363	-1.67	3.21	9.44	9.58
12	14	68	366	-1.83	2.51	9.44	9.44
12	16	68	368	-2.07	2.41	9.44	9.44
12	18	68	370	-5.54	-4.45	9.44	9.44
12	21	68	373	-6.64	-5.01	9.44	9.44
12	23	68	375	-5.94	-4.87	9.44	9.44
12	26	68	378	-10.82	-10.20	9.44	9.30
12	28	68	380	-15.84	-14.63	9.44	9.30
12	31	68	383	-13.74	.81	9.44	9.44

MONTH	DAY	YEAR	DAYS	SURFACE	COLLAR	48 FT	96 FT
1	2	69	384	-2.61	.81	9.58	9.44
1	4	69	386	2.71	.81	9.58	9.58
1	6	69	388	-.59	.81	9.58	9.58
1	8	69	390	-.93	.81	9.58	9.58
1	11	69	393	-1.02	.72	9.58	9.58
1	13	69	395	-1.10	.54	9.58	9.58
1	15	69	397	-1.26	.63	9.58	9.58
1	18	69	400	-2.92	.45	9.58	9.71
1	20	69	402	-7.80	.00	9.71	9.71
1	22	69	404	-13.47	-.16	9.71	9.71
1	25	69	407	-14.64	-.42	9.71	9.71
1	27	69	409	-10.15	-.85	9.71	9.71
1	29	69	411	-13.52	-.93	9.71	9.71
2	1	69	413	-12.61	-1.02	9.58	9.58
2	3	69	415	-12.61	-1.02	9.58	9.58
2	5	69	417	-12.85	-1.02	9.44	9.58
2	8	69	420	-12.15	-1.02	9.44	9.58
2	10	69	422	-10.15	-1.18	9.58	9.58
2	12	69	424	-6.70	-1.18	9.58	9.58
2	15	69	427	-2.53	-1.34	9.58	9.58
2	17	69	429	-4.03	-1.34	9.44	9.58
2	19	69	431	-6.07	-1.42	9.44	9.58
2	22	69	434	-6.70	-1.42	9.44	9.58
2	24	69	436	-6.07	-1.18	9.58	9.58
2	26	69	438	-5.07	-1.18	9.58	9.58
3	1	69	443	-4.66	-.85	9.58	9.58
3	3	69	445	-4.66	-.59	9.58	9.58
3	5	69	447	-4.66	-.59	9.58	9.58
3	8	69	450	-4.66	-.59	9.58	9.58
3	10	69	452	-4.03	-.50	9.58	9.58
3	12	69	454	-4.03	-.50	9.58	9.58
3	15	69	457	-4.66	-.59	9.58	9.58
3	17	69	459	-4.59	-.59	9.58	9.58
3	19	69	461	-4.59	-.59	9.58	9.58
3	22	69	464	-4.59	-.59	9.58	9.58
3	24	69	466	-4.03	-.50	9.58	9.58
3	26	69	468	-3.66	-.50	9.58	9.58
3	27	69	469	-3.66	-.42	9.58	9.58
3	31	69	473	-3.52	-.42	9.58	9.58
4	4	69	476	-3.44	-.42	9.58	9.58
4	5	69	477	-3.22	-.42	9.58	9.58
4	7	69	479	-3.22	-.42	9.58	9.58
4	9	69	481	-2.99	-.33	9.58	9.58
4	12	69	484	-2.92	-.16	9.58	9.58
4	14	69	486	-2.69	-.16	9.58	9.58
4	16	69	488	-2.30	.37	9.58	9.58
4	19	69	491	-2.15	.37	9.58	9.58
4	21	69	493	2.15	1.46	9.58	9.58
4	23	69	495	-2.07	1.46	9.58	9.58
4	26	69	498	-1.10	1.08	9.58	9.58
4	28	69	500	-.50	1.93	9.58	9.58

MONTH	DAY	YEAR	DAYS	SURFACE	COLLAR	48 FT	96 FT
4	30	69	502	6.99	2.31	9.58	9.58
5	3	69	505	8.24	2.71	9.58	9.58
5	5	69	507	8.76	2.90	9.58	9.58
5	7	69	509	9.58	3.51	9.58	9.71
5	10	69	512	11.88	4.14	9.58	9.71
5	12	69	514	15.89	4.79	9.58	9.71
5	14	69	516	18.82	5.69	9.58	9.71
5	17	69	519	27.90	6.15	9.58	9.71
5	19	69	521	24.73	6.51	9.58	9.71
5	21	69	523	30.47	7.11	9.58	9.71
5	24	69	526	33.73	7.73	9.58	9.71
5	26	69	528	26.97	8.37	9.44	9.71
5	28	69	530	23.92	8.89	9.44	9.58
5	31	69	533	23.41	9.16	9.30	9.58

MONTH	DAY	YEAR	DAYS	158 FT	210 FT	218 FT	226 FT
3	16	68	98	10.41	11.86	11.13	10.84
3	17	68	99	10.41	11.86	11.13	10.84
3	18	68	100	10.41	11.86	11.13	10.84
3	19	68	101	9.99	11.28	10.84	10.41
3	20	68	102	10.27	11.43	10.98	10.84
3	21	68	103	10.27	11.43	10.98	10.84
3	22	68	104	9.99	11.43	10.98	10.84
3	23	68	105	9.99	11.13	10.84	10.41
3	24	68	106	9.99	11.43	10.98	10.84
3	25	68	107	9.99	11.28	10.98	10.84
3	26	68	108	9.85	11.13	10.41	10.70
3	27	68	109	9.99	11.28	10.84	10.84
3	28	68	110	10.41	11.86	10.98	10.84
3	29	68	111	10.41	11.86	10.98	10.84
3	30	68	112	10.41	11.86	10.98	10.84
3	31	68	113	10.27	12.19	10.98	10.84
4	1	68	114	10.27	11.43	10.98	10.84
4	2	68	115	10.27	11.58	10.98	10.84
4	3	68	116	10.97	11.58	10.98	10.84
4	4	68	117	10.41	12.19	10.98	10.84
4	5	68	118	10.41	12.19	10.98	10.84
4	6	68	119	10.41	12.34	10.98	10.84
4	7	68	120	10.41	12.50	11.13	10.98
4	9	68	122	10.41	12.34	11.13	10.98
4	10	68	123	10.41	12.19	11.13	10.98
4	11	68	124	10.84	12.34	11.13	11.13
4	12	68	125	10.56	12.34	11.13	11.13
4	13	68	126	10.41	12.34	11.13	10.98
4	14	68	127	10.70	12.34	11.13	10.98
4	15	68	128	10.70	12.50	11.13	10.98
4	16	68	129	10.70	12.66	11.13	11.13
4	17	68	130	10.56	12.66	11.13	11.13
4	18	68	131	10.56	12.66	11.13	11.13
4	19	68	132	10.41	12.66	11.13	11.13
4	20	68	133	10.41	12.66	11.13	11.13
4	21	68	134	10.41	12.66	11.13	10.98
4	22	68	135	10.41	12.34	11.13	10.98
4	23	68	136	14.14	12.34	11.13	10.98
4	24	68	137	10.41	12.19	11.13	10.98
4	25	68	138	10.41	12.19	11.13	10.84
4	26	68	139	10.41	12.03	11.13	10.84
4	27	68	140	10.41	12.34	11.13	10.98
4	28	68	141	10.40	12.66	10.98	10.98
4	29	68	142	10.41	12.50	10.84	10.98
4	30	68	143	10.41	12.50	10.84	10.98
5	1	68	144	10.41	12.50	10.84	10.98
5	4	68	147	10.41	12.50	11.13	10.98
5	6	68	149	10.41	12.66	11.13	11.13
5	8	68	151	10.41	12.66	10.98	11.13
5	10	68	153	10.41	12.66	11.13	10.98

MONTH	DAY	YEAR	DAYS	158 FT	210 FT	218 FT	226 FT
5	13	68	156	10.41	12.50	11.13	10.98
5	15	68	158	10.41	12.50	11.13	11.13
5	27	68	160	10.41	12.50	10.98	10.98
5	20	68	163	10.41	12.50	10.98	10.98
5	22	68	165	10.41	12.50	10.98	10.98
5	24	68	167	10.41	12.50	10.98	10.98
5	27	68	170	10.41	12.66	11.13	10.98
5	29	68	172	10.41	12.66	11.13	10.98
5	31	68	174	10.41	12.66	11.13	10.98
6	3	68	176	10.41	12.50	10.98	10.98
6	5	68	178	10.41	12.50	11.13	10.98
6	8	68	181	10.41	12.50	10.98	10.98
6	10	68	183	10.41	12.50	10.98	10.98
6	12	68	185	10.41	11.88	10.98	10.98
6	25	68	188	10.41	11.88	10.98	10.98
6	17	67	190	10.41	11.88	10.98	10.98
6	29	68	192	10.41	12.03	10.98	10.98
6	25	68	198	10.41	11.58	10.41	10.70
6	28	68	201	10.41	11.58	10.84	10.84
7	1	68	204	10.41	11.58	10.84	10.84
7	4	68	207	10.27	11.58	10.84	10.84
7	6	68	209	10.27	11.58	10.84	10.84
7	8	68	211	10.41	11.58	10.84	10.84
7	11	68	214	10.70	11.58	10.41	10.98
7	13	68	216	10.56	11.58	10.41	10.98
7	16	68	219	10.56	11.58	10.41	10.98
7	18	68	221	10.56	11.58	10.41	10.98
7	20	68	223	10.70	11.58	10.56	10.98
7	22	68	225	10.70	11.58	10.56	10.98
7	25	68	228	10.84	11.13	10.70	11.13
7	27	68	230	10.84	11.13	10.70	11.13
7	30	68	233	10.84	11.13	10.70	11.13
8	1	68	234	10.84	11.13	10.70	10.98
8	3	68	236	10.70	11.13	10.70	10.98
8	6	68	239	10.70	11.13	10.70	11.13
8	8	68	241	10.70	11.13	10.84	10.98
8	10	68	243	10.84	11.13	10.98	10.98
8	13	68	246	10.84	10.98	11.13	10.98
8	15	68	248	10.84	10.98	11.13	10.98
8	17	68	250	10.84	10.98	11.13	10.98
8	24	68	256	10.84	9.58	10.98	11.13
8	27	68	259	10.70	8.37	10.98	10.98
8	29	68	261	10.70	8.37	10.98	10.98
8	31	68	263	10.70	8.37	10.98	10.98
9	3	68	265	10.70	8.24	10.98	10.98
9	5	68	267	10.70	8.24	10.98	10.98
9	7	68	269	10.70	8.24	10.98	10.98
9	10	68	272	10.84	7.98	10.98	10.98
9	12	68	274	10.84	7.73	10.98	11.13

MONTH	DAY	YEAR	DAYS	158 FT	210 FT	218 FT	226 FT
9	14	68	276	10.84	7.36	10.89	11.13
9	17	68	279	10.84	7.36	10.98	11.13
9	19	68	281	10.84	7.36	10.98	11.13
9	21	68	283	10.84	6.75	11.13	11.13
9	24	68	286	10.84	6.15	11.13	11.13
9	26	68	288	10.84	6.15	11.13	11.13
9	28	68	290	10.84	6.04	11.13	11.13
10	1	68	293	10.84	6.04	11.13	11.13
10	3	68	295	10.84	6.04	11.13	11.13
10	5	68	297	10.98	6.04	11.28	11.43
10	7	68	299	10.84	5.92	11.13	11.13
10	9	68	391	10.84	5.92	11.13	11.28
10	12	68	304	10.84	5.69	11.13	11.13
10	14	68	306	10.84	5.58	10.98	11.13
10	16	68	308	10.84	5.69	10.98	10.98
10	19	68	311	10.84	5.69	11.13	10.98
10	21	68	313	10.84	5.35	11.13	11.13
10	23	68	315	10.84	5.35	11.13	11.28
10	26	68	318	10.84	5.01	11.13	11.28
10	28	68	320	10.84	4.58	11.13	11.28
10	30	68	322	10.84	4.47	11.13	11.28
11	2	68	324	10.84	4.25	11.28	11.58
11	4	68	326	10.84	4.25	11.28	11.58
11	6	68	369	10.84	4.25	11.28	11.88
11	9	68	335	10.84	4.03	11.73	11.88
11	11	68	333	10.84	4.03	11.73	11.88
11	13	68	335	10.84	4.03	11.88	11.88
11	16	68	338	10.84	4.03	11.88	11.88
11	18	68	340	10.84	3.93	12.03	11.88
11	20	68	342	10.84	3.93	12.03	11.58
11	23	68	345	10.84	3.72	12.19	11.43
11	25	68	347	10.84	3.51	12.19	11.58
11	27	68	349	10.84	3.41	12.19	11.73
11	30	68	352	10.84	3.21	12.19	11.73
12	2	68	354	10.84	3.21	12.02	11.73
12	4	68	356	10.70	3.21	11.73	11.73
12	7	68	359	10.70	3.21	11.58	11.73
12	9	68	361	10.70	3.21	11.58	11.58
12	11	68	363	13.70	3.21	11.58	11.73
12	14	68	366	10.70	2.71	11.43	11.73
12	16	68	368	10.70	2.80	11.43	11.73
12	18	68	370	10.70	2.80	11.43	11.73
12	21	68	373	10.56	2.71	11.28	11.73
12	23	68	375	10.70	2.61	11.28	11.58
12	26	68	378	10.56	2.61	11.28	11.58
12	28	68	380	10.41	2.51	11.73	11.58
12	31	68	383	10.84	1.74	10.98	11.73
1	2	69	384	10.98	1.83	10.98	11.73
1	4	69	386	10.98	1.83	10.84	11.88
1	6	69	388	10.98	1.83	10.84	11.88
1	8	69	390	10.98	1.83	10.84	11.88

MONTH	DAY	YEAR	DAYS	158 FT	210 FT	218 FT	226 FT
1	11	69	393	10.98	1.74	10.84	11.88
1	13	69	395	10.98	1.74	10.70	11.88
1	15	69	397	10.98	1.74	10.70	11.88
1	18	69	400	10.98	1.74	10.41	12.03
1	20	69	402	10.98	1.55	10.41	12.03
1	22	69	404	10.98	1.55	10.41	12.03
1	25	69	407	10.98	1.55	9.85	12.03
1	27	69	409	10.98	1.46	9.85	12.03
1	29	69	411	10.98	1.46	9.85	12.03
2	1	69	413	10.98	1.27	9.85	11.88
2	3	69	415	10.70	0.81	9.44	11.58
2	5	69	417	10.70	0.63	9.03	11.88
2	8	69	420	10.70	0.37	8.76	11.88
2	10	69	422	10.70	0.00	8.50	11.88
2	12	69	424	10.70	-.08	8.37	11.58
2	15	69	427	10.70	-.08	8.11	11.58
2	17	69	429	10.48	-.16	8.11	11.58
2	19	69	431	10.84	-.16	7.98	11.73
2	22	69	434	10.98	-.16	7.98	11.73
2	24	69	436	10.98	-.33	8.11	11.73
2	26	69	438	10.98	-.33	8.11	11.73
3	1	69	443	10.84	-.50	8.24	11.88
3	3	69	475	10.84	-.50	8.24	11.88
3	5	69	447	10.84	-.50	8.24	11.88
3	8	69	450	10.84	-.50	8.24	11.88
3	10	69	452	10.84	-.50	8.11	11.88
3	12	69	454	10.84	-.50	8.11	11.88
3	15	69	457	10.70	-.50	8.11	11.88
3	17	69	459	10.70	-.50	8.11	11.88
3	19	69	461	10.70	-.50	8.11	11.88
3	22	69	464	10.70	-.50	8.11	11.88
3	24	69	466	10.70	-.50	8.11	11.88
3	26	69	468	10.70	-.50	8.11	11.88
3	29	69	469	10.70	-.50	8.11	11.88
3	31	69	473	10.70	-.50	8.11	11.88
4	4	69	476	10.70	-.50	8.11	11.88
4	5	69	477	10.70	-.50	8.11	11.88
4	7	69	479	10.70	-.50	8.11	11.88
4	9	69	481	10.70	-.50	8.11	11.88
4	12	69	484	10.70	-.50	8.11	11.88
4	14	69	486	10.70	-.50	8.11	11.88
4	16	69	488	10.70	-.50	8.11	11.88
4	19	69	491	10.70	-.50	8.11	11.88
4	21	69	493	10.70	-.50	8.11	11.88
4	23	69	495	10.70	-.50	8.11	11.88
4	26	69	498	10.70	-.50	8.11	11.88
4	28	69	500	10.70	-.50	7.98	11.88
4	30	69	502	10.70	-.76	7.98	11.88
5	3	69	505	10.70	-.76	7.60	11.88
5	5	69	507	10.70	-.76	7.60	11.88

MONTH	DAY	YEAR	DAYS	158 FT	210 FT	218 FT	226 FT
5	7	69	509	10.70	-1.18	7.60	11.88
5	10	69	512	10.70	-1.42	7.11	11.43
5	12	69	514	10.84	-1.75	6.63	11.43
5	14	69	516	10.84	-1.91	6.15	11.43
5	17	69	519	10.84	-2.30	5.69	11.13
5	19	69	521	10.98	-2.45	5.24	11.13
5	21	69	523	10.98	-2.84	4.79	11.13
5	24	69	526	10.98	-3.22	3.82	10.98
5	26	69	528	10.98	-3.22	3.82	10.84
5	28	69	530	10.84	-3.51	3.72	10.84
5	31	69	533	10.70	-3.66	3.41	10.84

LITHIFIED SHALE PROJECT

APPENDIX F

WATER LEVEL - TEST AND UNDISTURBED SITES

APPENDIX F

GROUND WATER LEVEL DATA

MONTH	DAY	YEAR	DAYS	TEST SITE	UNDISTURBED SITE
8	20	68	251		
8	24	68	255	8.5	18.6
8	27	68	258	8.7	18.5
8	29	68	260	8.6	18.6
8	31	68	262	8.8	18.6
9	3	68	264	8.7	18.6
9	5	68	266	8.9	18.7
9	7	68	268	8.8	18.6
9	10	68	271	8.7	18.8
9	12	68	273	8.9	18.9
9	14	68	275	8.8	19.0
9	17	68	278	8.8	19.0
9	19	68	280	8.7	18.9
9	21	68	282	8.6	19.0
9	24	68	285	8.6	19.1
9	26	68	287	8.7	19.0
9	28	68	289	8.5	18.9
10	1	68	292	8.6	18.8
10	3	68	294	8.4	18.9
10	4	68	295	8.5	19.0
10	5	68	296	8.5	19.0
10	9	68	300	8.4	19.0
10	12	68	303	8.4	19.0
10	14	68	305	8.4	19.0
10	16	68	307	8.3	18.9
10	19	68	310	8.3	18.9
10	21	68	312	8.3	18.9
10	23	68	314	8.3	18.9
10	26	68	317	8.4	18.9
10	28	68	319	8.3	18.9
10	30	68	321	8.3	18.8
11	2	68	323	8.2	18.8
11	4	68	325	8.1	18.4
11	6	68	327	8.2	18.0
11	9	68	330	8.1	17.3
11	11	68	332	8.1	16.5
11	13	68	334	8.1	16.1
11	16	68	337	8.1	15.9
11	18	68	339	8.0	15.1
11	20	68	341	8.1	15.1

MONTH	DAY	YEAR	DAYS	TEST SITE	UNDISTURBED SITE
11	23	68	344	8.1	15.3
11	25	68	346	8.0	15.4
11	27	68	348	8.0	15.4
11	30	68	351	8.0	15.4
12	2	68	353	8.0	15.5
12	4	68	355	7.9	15.5
12	7	68	358	7.9	15.5
12	9	68	360	7.9	15.5
12	11	68	362	7.9	15.5
12	14	68	365	7.9	15.7
12	16	68	367	7.9	15.7
12	18	68	369	7.9	15.7
12	21	68	372	7.9	15.7
12	23	68	374	7.9	15.9
12	26	68	377	7.9	15.9
12	28	68	379	7.9	15.9
12	31	68	382	7.9	16.0
1	2	69	383	7.8	16.0
1	4	69	385	7.8	16.0
1	6	69	387	7.8	16.0
1	8	69	389	7.8	16.0
1	11	69	392	7.8	16.1
1	13	69	394	7.8	16.1
1	15	69	396	7.8	16.3
1	18	69	399	7.8	16.3
1	20	69	401	7.8	16.3
1	22	69	403	7.7	16.3
1	25	69	406	7.7	16.3
1	27	69	408	7.7	16.4
1	29	69	410	7.7	16.4
2	1	69	412	7.7	16.4
2	3	69	414	7.7	16.4
2	5	69	416	7.7	16.5
2	8	69	419	7.8	16.5
2	12	69	424	7.8	16.6
2	15	69	427	7.8	16.7
2	17	69	429	7.8	16.7
2	19	69	431	7.8	16.7
2	22	69	434		16.7
2	24	69	436		16.6
2	26	69	438		16.6
3	1	69	443		16.5
3	3	69	445		15.2
3	5	69	447		12.6
3	8	69	450	7.5	10.7
3	10	69	452	7.6	7.8
3	12	69	454	7.6	7.3
3	15	69	457	7.6	6.8
3	17	69	459	7.5	6.3
3	19	69	461	7.5	5.9

MONTH	DAY	YEAR	DAYS	TEST SITE	UNDISTURBED SITE
3	22	69	464	7.5	6.0
3	24	69	466	7.5	6.1
3	26	69	468	7.5	6.1
3	29	69	469	7.5	6.1
3	31	69	473	7.5	6.1
4	4	69	476	7.5	6.3
4	5	69	477	7.6	6.3
4	7	69	479	7.6	6.2
4	9	69	481	7.6	6.2
4	12	69	484	7.6	6.2
4	14	69	486	7.5	6.2
4	16	69	488	7.5	6.2
4	19	69	491	7.5	6.2
4	21	69	493	7.5	6.2
4	23	69	495	7.5	6.2
4	26	69	498	7.5	6.2
4	28	69	500	7.5	6.2
4	30	69	502	7.5	6.2
5	3	69	505	7.5	6.3
5	5	69	507	7.5	6.3
5	7	69	509	7.6	6.3
5	10	69	512	7.6	6.3
5	12	69	514	7.6	6.3
5	14	69	516	7.6	6.3
5	17	69	519	7.6	6.4
5	19	69	521	7.6	6.4
5	21	69	523	7.6	6.4
5	24	69	526	7.6	6.4
5	26	69	528	7.5	6.5
5	28	69	530	7.5	6.5
5	31	69	533	7.5	6.5